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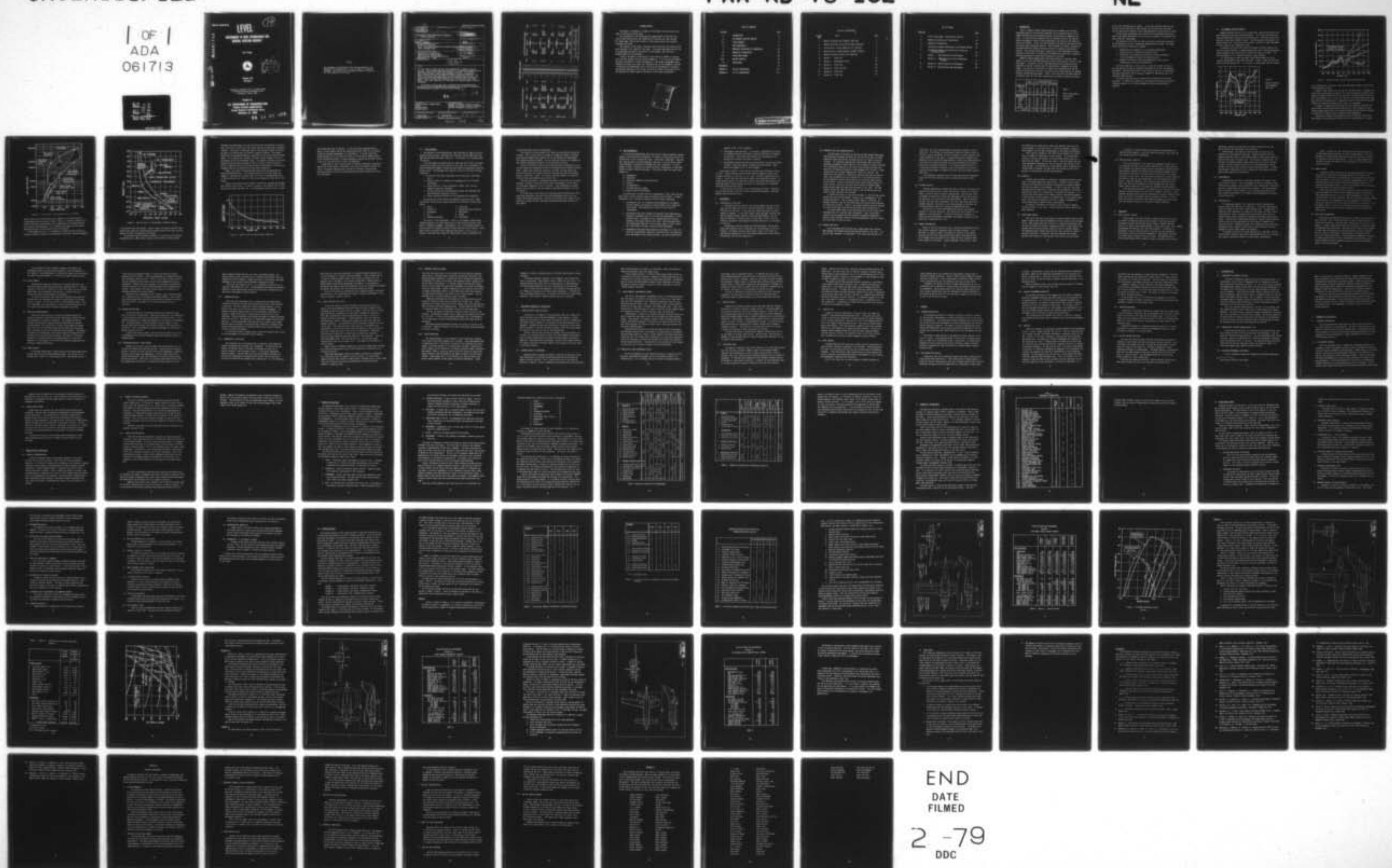

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ASSESSMENT OF NEW TECHNOLOGIES FOR GENERAL AVIATION AIRCRAFT

Karl H. Bergey

September 1978
Final Report

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16. Abstract

This report assesses the use of new technologies in general aviation aircraft. It also investigates the potential for a technology demonstration program aimed specifically at the needs of general aviation. It concludes that at least 46 new or under-used technologies could be incorporated in general aviation aircraft with benefit to safety, performance and cost. The rate at which these new technologies might be integrated into the fleet will depend on social and political trends as well as on the technologies themselves. This report identifies 22 trends that will influence general aviation development.

On the basis of the study results it appears that joint demonstration programs involving the FAA, NASA and industry would be valuable in introducing new technologies into general aviation aircraft design.

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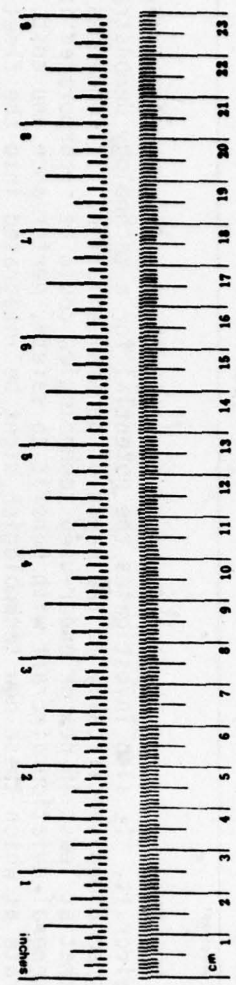
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

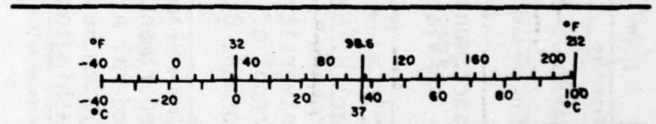
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ACKNOWLEDGMENTS

The author is indebted to a number of individuals for advice and assistance in carrying out this study.

The initiative of "JB" McCollough and Joseph Howell of the FAA's Aircraft Flight Safety Branch was responsible for getting the study started. Mr. McCollough's advice and his help in identifying sources were valuable throughout the study.

The students in the author's Aerospace Vehicle Design class (Spring 1978) were involved in all aspects of the study. The author would particularly like to acknowledge the help of John Haskell, David McGhee, James Phillips, Michael Rieger and William Weiss.

Finally, the author relied heavily on the advice of leaders in the general aviation industry and the research community. A list of the contributors and their affiliation is given in Appendix B. The author acknowledges their valuable assistance, but takes full responsibility for the judgments involved in selecting the technologies and in resolving the differences in viewpoint. The opinions expressed in this report are entirely those of the author and do not necessarily reflect those of the FAA or of any single contributor.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. INTRODUCTION

The U.S. Federal Aviation Administration has a mandate to anticipate regulatory needs for the aviation community and to encourage the use of advanced engineering and operational concepts in the design of commerical aircraft. To carry out this responsibility for general aviation, the FAA must assess the potential impact of new technologies, particularly with regard to utility and safety. It has also been suggested from time-to-time that the FAA, along with other government agencies, should promote the design, construction and demonstration of advanced concept aircraft for general aviation applications. Such programs have been a regular part of the Department of Transportation's activities in fostering new transportation modes and in demonstrating new approaches to established transportation systems.

General aviation demonstrators have been effective in the past, most notably in the joint FAA-USDA-industry program on agricultural aircraft in the late 1940's. The results of this combined program was the design and construction of the AG-1 airplane and its demonstration throughout the United States. As a result of this effort to improve the crashworthiness and the utility of agricultural aircraft, the nature of ag airplane design was changed radically during the next decade. Table 1 shows the factor-of-three reduction in fatality rates for the "new" configuration ag planes as compared to those

	Total Accidents	Pilot Injury Ratios		
		Fatal	Serious	Minor/None
Conventional				
PA-18	734	.214	.126	.660
Aeronca	47	.127	.255	.618
Total	781	.209	.135	.656
New Generation				
Ag-Wagon	43	.093	.116	.791
Pawnee	584	.068	.096	.836
Snow	88	.159	.090	.751
Callair	216	.069	.088	.843
Ag Cat	183	.011	.044	.945
Total	1114	.067	.086	.847

TABLE I

Pilot Injury Rates-
Agricultural
Aircraft.

of the "old" configuration ag planes. It has been estimated that over the ten year period from 1960 to 1969, between 160 and 200 pilots owed their lives to the survival features of the new generation of agricultural aircraft.

No equivalent program has been carried out for passenger-carrying aircraft, even though the potential for saving lives appears to be greater than that of the AG-1 development.

The purpose of this study has been to provide a preliminary evaluation of the feasibility of such a technology demonstration aircraft. The study itself consisted of three basic elements:

1. Compilation of a complete list of advanced technologies suitable for use in general aviation aircraft.
2. Evaluation of the potential contribution of each technology to the improvement of general aviation aircraft.
3. Synthesis of the most promising technologies into a set of representative aircraft configurations.

Since the study was carried out over a very short period of time, it was not possible to make an exhaustive assessment of all the technologies considered. The more modest goal of the study has been to list potentially important technologies and to develop a method for considering them in a relatively objective way.

The short study period also increased the likelihood of errors and omissions. To reduce this possibility, the author has sought the advice of recognized experts in all fields of general aviation and aeronautical research.

II. THE GENERAL AVIATION INDUSTRY

General aviation consists of all non-military, non-airline aircraft and their supporting industries and organizations. It includes fixed-wing aircraft and rotorcraft, homebuilts and executive jets. The total active fleet consists of more than 180,000 aircraft. The FAA estimates that general aviation aircraft will fly about 40 million hours in 1978, six times the number of hours flown by the scheduled airlines.

In addition to the aircraft fleet, the general aviation industry consists of pilots (750,000), airframe manufacturers (20), fixed-base operators, service companies and flight schools (5,000) and airports (13,500). The total employment in U.S. general aviation is about 250,000.

U.S. manufacturers offer more than 120 different models at prices ranging from $14,000 to more than $5,000,000. Figure 1 shows the unit shipments from 1962 through 1977. The increase in recent years has been largely

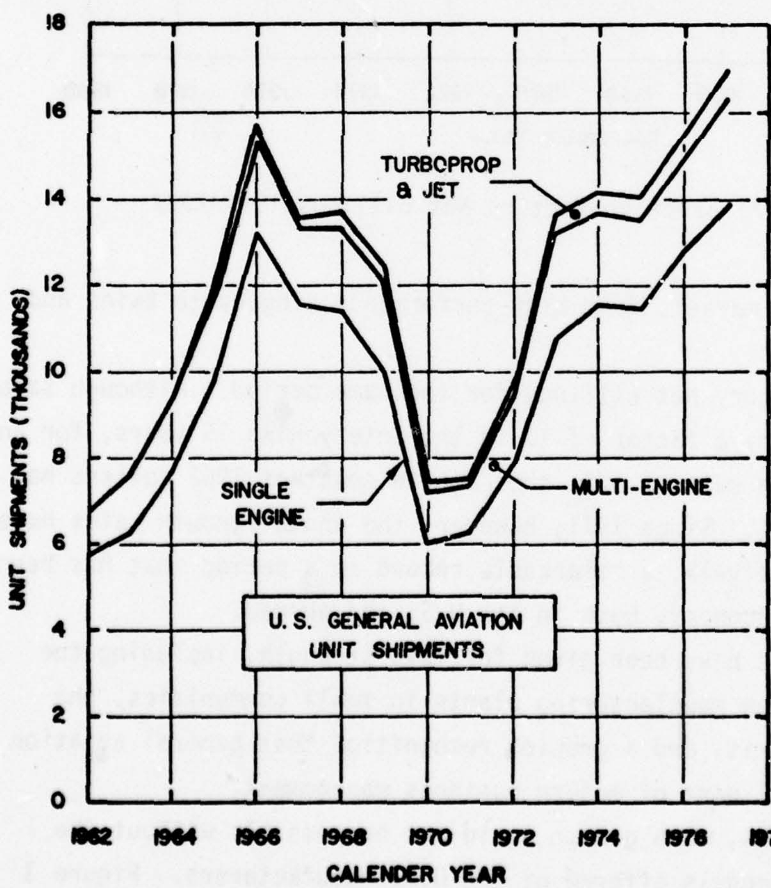


Figure 1.

General Aviation Unit Shipments 1967-1977

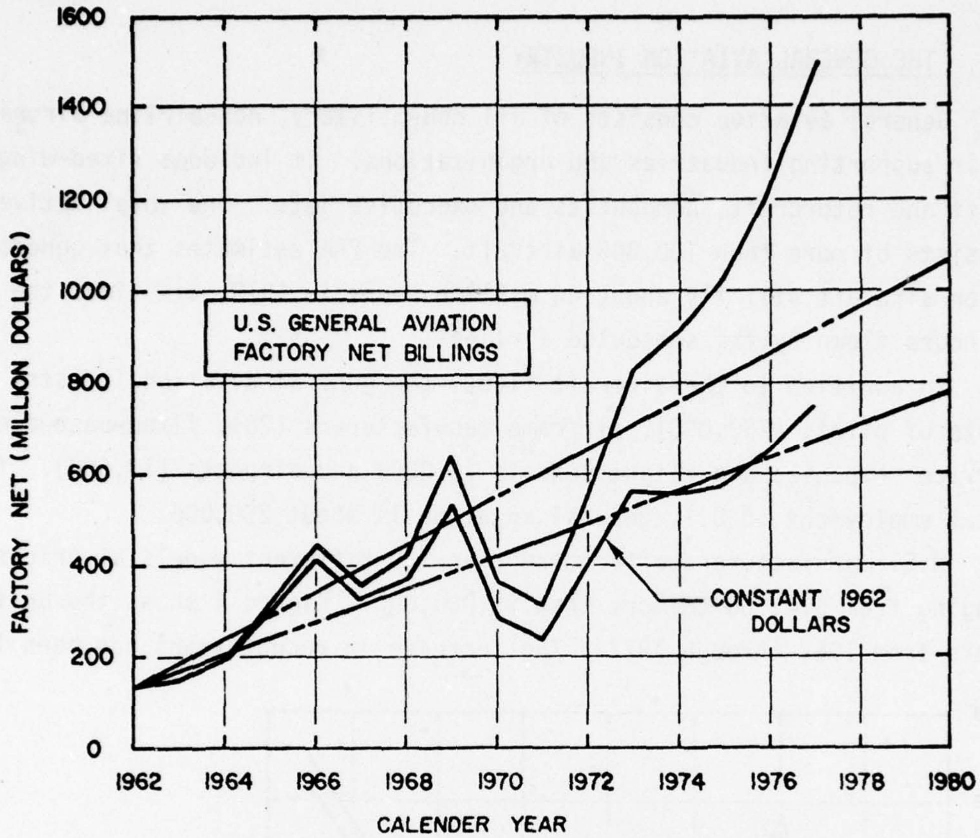


Figure 2. General Aviation Factory Net Billings 1967-1977

at the upper end of the market, from high-performance singles to twins and turbine-powered aircraft.

Figure 2 shows factory net billings for the same period. Although sales dollars have increased by a factor of 10 in the intervening 15 years, for an impressive annual growth rate of 17%, the rate in constant 1962 dollars has been a more modest 11.5%. Since 1971, however, the annual growth rates have been 31% and 22% respectively, a remarkable record in a period that has been marked by an uncertain economy, both in the U.S. and abroad.

A number of reasons have been given for this strength, including the trend toward locating new manufacturing plants in small communities, the 55 mph highway speed limit, and a growing recognition that general aviation aircraft are an integral part of modern business management.

Whatever the reasons, such growth would not be possible without the wide range of aircraft models offered by the U.S. manufacturers. Figure 3

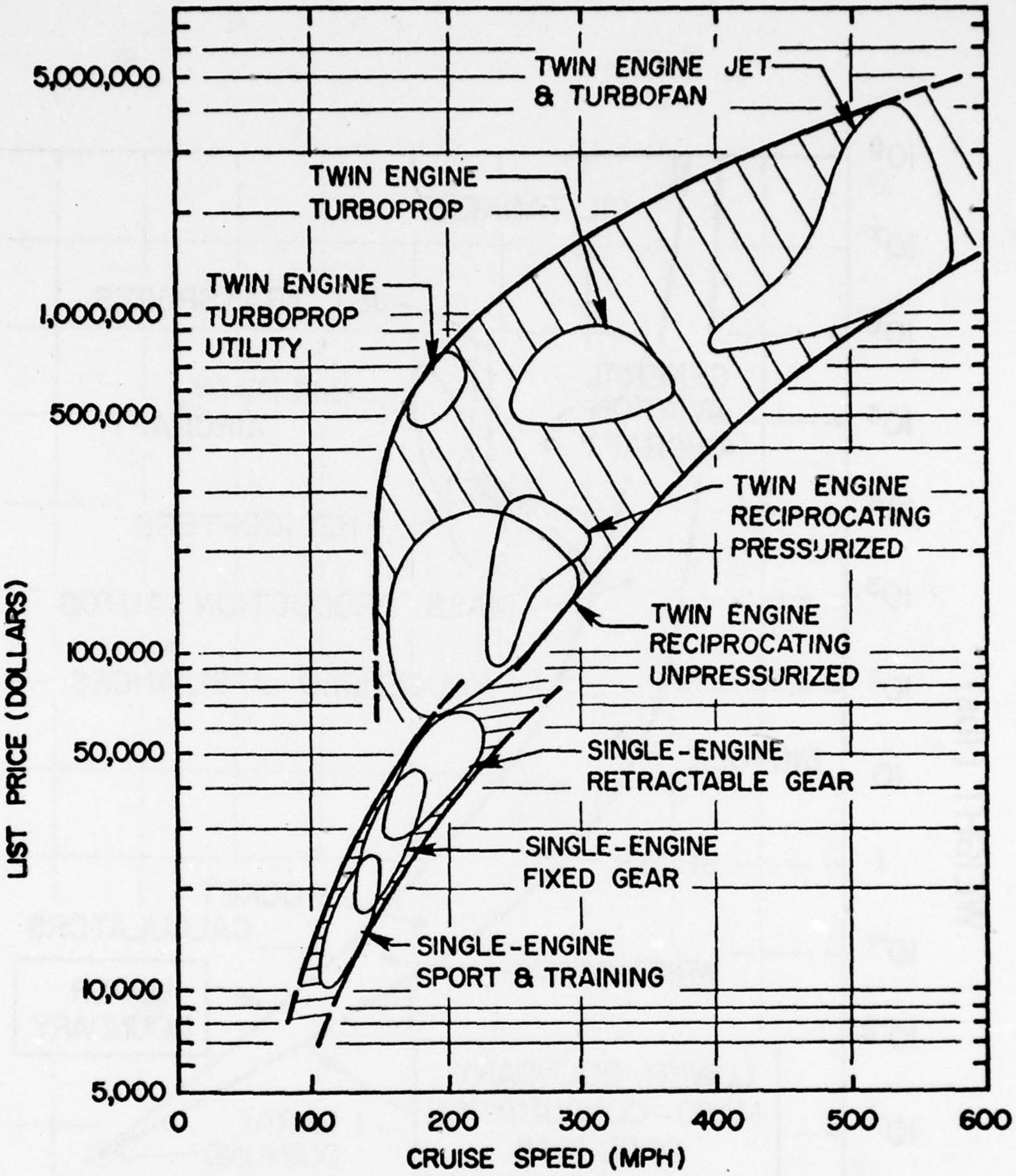


Figure 3. List Price vs. Cruise Speed for U. S. Aircraft

shows a plot of list price versus cruise speed for currently-available single-engine and twin engine aircraft. Models in a specific category fall within a relatively narrow range, but the boundaries for singles and twins are broad and non-overlapping. It is apparent that there are few performance/cost regions in which aircraft are not available.

On the matter of cost, it is important to recognize that aircraft are inherently expensive because of low production rates and a necessary emphasis

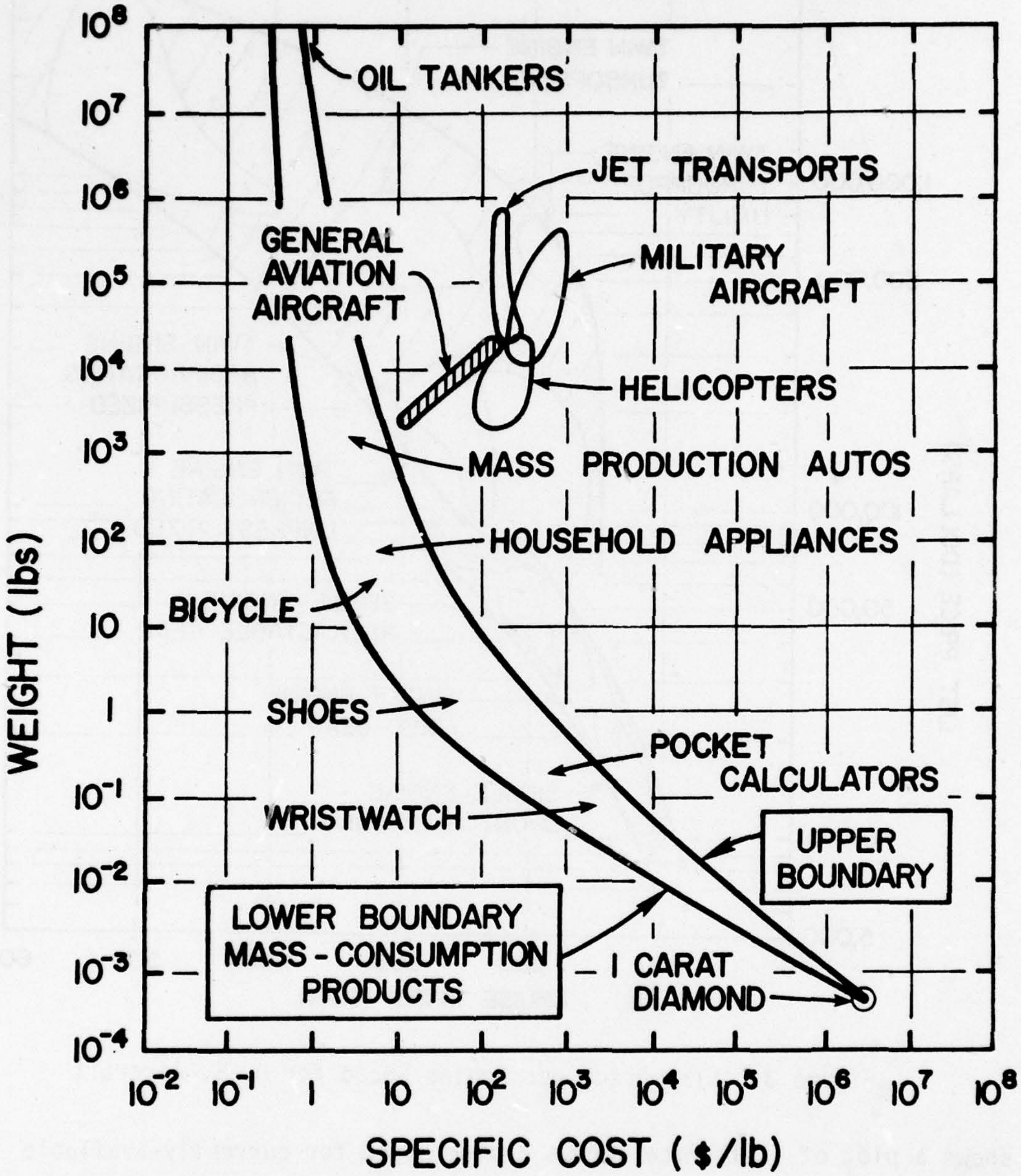


Figure 4. Specific Cost vs. Empty Weight, Consumer Products

on reliability and light weight. Figure 4 shows the range of specific costs (dollars per pound) for representative consumer products from ships and automobiles to shoes, wristwatches and diamonds.

Aircraft and high-performance automobiles are clearly outside the mass consumption band. What's more, despite the best efforts of many capable

designers and businessmen, the cost of aircraft has not declined in the past and is not likely to decline in the future relative to other mass-consumption products. Thus point is addressed later in the study but should in no sense be taken as pessimism about the future of general aviation. The current market and the government/industry projections for the future speak for themselves. It is unrealistic, however, to expect radical changes in cost or performance within the forseeable future. The economic realities of aircraft production and the evolving nature of the air traffic control system will place an effective limit on the aircraft market and therefore a limit on the economies that can be realized from large scale production.

Figure 4 is useful in assessing the potential for new approaches to design and manufacturing. If an airplane retails for $15 per pound, for example, a new material or process that will result in manufacturing costs of $25 per pound is not likely to find a wide acceptance in that part of the market.

Finally, the safety record of general aviation has improved considerably over the past thirty years. As shown in Figure 5, the fatality rate in 1976 was only one-fourth the 1946 rate. The improvement continues, but at a some-

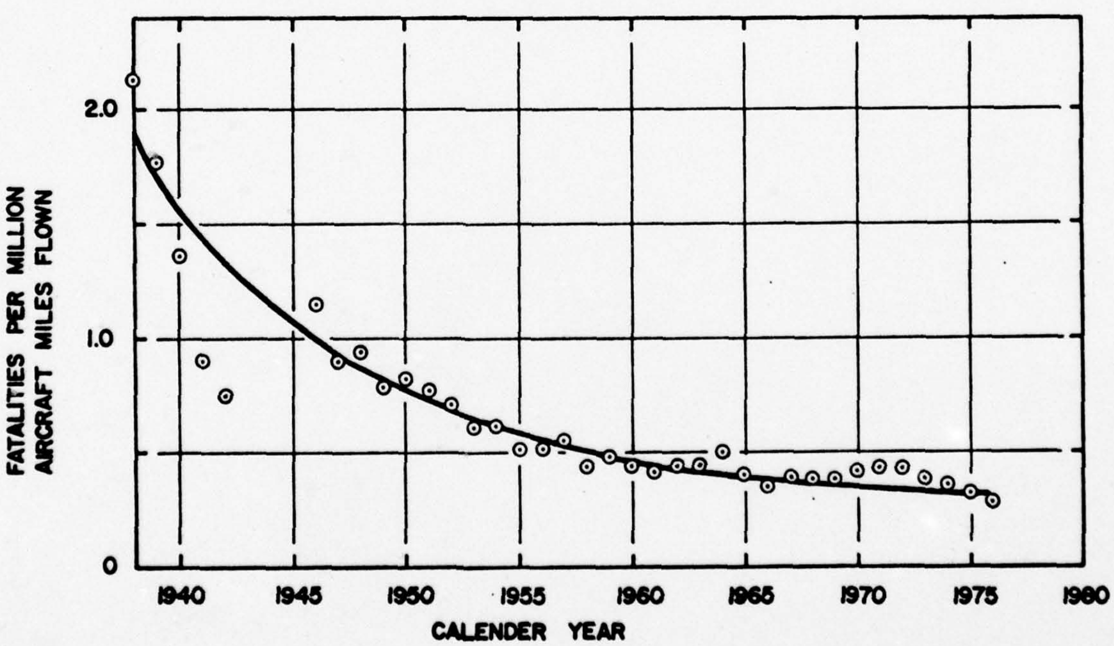


Figure 5. General Aviation Fatality Rate 1938-1976.

what slower pace than in the past. As the author has suggested before, there is some evidence that we are reaching the end of the line in accident prevention through improvements in airworthiness. If pilots ignore the safety features built into their aircraft, or if the safety features aren't having the desired effect, it seems reasonable to design new aircraft in such a way as to save the pilots in spite of themselves.

A major goal of this study has been to identify technologies that would improve the flight safety, performance, and utility of general aviation aircraft. An equally important goal has been to find ways in which crashworthiness features could be incorporated without serious penalties in cost and performance.

III STUDY APPROACH

We started by listing technologies that might have an impact on future general aviation design. Some were new, some were old-but-under-used, and some were borrowed from other industries. The original list contained about 135 entries.

Since the number of technologies was large and their effects on general aviation design were sure to be varied, it was clear that a reasonably objective method was needed to choose the most promising technologies from this diverse group. The procedure would need to satisfy at least the following conditions:

1. Allow each individual technology to be assessed on a consistent basis.
2. Provide a means for comparing the relative merits of different technologies.
3. Insure that all critical performance, safety, cost, and use categories would be considered.
4. Provide a method for differentiating between most important and least important evaluation criteria.
5. Permit sensitivity testing for key parameters and assumptions.

The criteria by which aircraft are judged are varied at best. After considerable discussion and experimentation, ten evaluation criteria were chosen:

1.	Safety	6.	Efficiency
2.	Reliability	7.	Operational Ease & Utility
3.	Performance	8.	Maintenance
4.	Cost	9.	Weight
5.	Customer Acceptance	10.	Environment

The choice is far from perfect. There is, for example, some overlap between categories, and their application for this purpose requires large doses of subjective judgment. Nevertheless, each is an important factor in the sale and use of general aviation aircraft and none can be ignored. Since some criteria are clearly more important than others, it was necessary to develop a rank order and a means for taking their relative importance into

consideration when selecting technologies.

The original list was reduced to 52 items by using various elimination criteria. This list was then circulated to a number of people in the general aviation community for comment and for the addition of technologies that might have been overlooked. We also asked our advisors for comments on the relative importance of each of the 10 evaluation criteria.

Finally, we tried to identify the trends that would influence the rate at which these new technologies might be introduced into the general aviation fleet. Some of the trends were technical, but most involved social and political pressures that might themselves influence the nature of aircraft design in the future. Again, our advisors were most helpful in selecting critical trends and adding to our original list.

From the large mass of information generated at this point of the study, we began to assess all the technologies that had appeared on our original list and those suggested by our contributors. Each technology was judged against the 10 criteria using the numerical evaluation procedure described in Section V.

The final step in the study was to develop various configurations that might take advantage of the most promising technologies and also be consistent with trends noted above. Section VIII describes this aspect of the study and includes the four technology demonstration designs selected for this report.

IV NEW TECHNOLOGIES

A list of new technologies that could have an effect on general aviation design is relatively easy to generate. As noted in the previous section, we started with a total of about 135 items. Contributors added more. Some were new, some had been tried and abandoned, some were in use but had not found wide acceptance, and some were borrowed from other industries. All were thought to have a potential for improving safety, performance, or some other aspect of general aviation operations. They were divided into seven broad categories:

A. Aerodynamics

B. Powerplant

C. Structures, Materials and Fabrication

D. Avionics

E. Instrumentation

F. Airframe Design & Systems

G. Human Factors and Operations

The problem was to select from this smorgasbord of ideas those few that were likely to have a genuine impact on general aviation design. To make a preliminary cut, a few basic elimination criteria were established.

1. Technologies that are already gaining acceptance in the general aviation industry and would not benefit greatly from a demonstration program. Area navigation is typical of this class of technologies.
2. Technologies that would probably not benefit from a demonstration program of reasonable size, or for which the marketplace is a more suitable arena. An example of this category would be low-cost turbines in the large executive jet class. Most corporate owners have demonstrated that cost is not a major factor in their search for a high level of safety, reliability and performance.
3. Improvements that would more properly be included in a "wish list", since our investigation turned up no technical basis for expecting major improvements over existing systems. Low cost pressurization

appears to fall in this category.

4. Technologies that have been - or are being - developed for military or transport aircraft, but appear to have little merit for general aviation use. Full-time active controls for the purpose of reducing tail size and cruise drag is typical.

5. Technologies that are interesting and even useful, but are not likely to have a significant impact on general aviation design. Fiber optics are judged to fall in this category.

Using these criteria, it was possible to reduce the preliminary list to 52 items. Further additions and deletions based on comments from our contributors resulted in a net loss of six items, leaving a total of 46 technologies. Each of them has been tested against the elimination criteria. In a more positive sense, it is possible to say that each has the potential for improving general aviation design and should be considered for an advanced technology demonstration program.

A short discussion of each of the 46 technologies follows. Appendix A contains discussions of some of the more significant technologies that were deleted from the original lists.

A. AERODYNAMICS

A-1 SPOILERS/FULL SPAN FLAPS

The substitution of spoilers for ailerons permits the use of full-span trailing edge flaps, with a resulting increase in maximum lift coefficient for the wing. If the wing area remains the same, the stall speeds are reduced. If the stall speed is kept the same, the wing area may be reduced, thereby increasing high speed performance. The potential reduction in landing speed is on the order of 8% to 10%; the potential increase in high speed with reduced wing area is on the order of 2% to 3%.

The design of spoiler systems to avoid aerodynamic lag and other undesirable effects can be a challenge, but the technology is well developed. For general aviation applications, there is no reason for spoiler/flap combinations to be more complex mechanically than the more conventional aileron/flap combinations.

A-2 IMPROVED STALL/SPIN CHARACTERISTICS

An NTSB study of accidents for the period 1967 through 1969 showed that stall/spin accidents accounted for only 8% of the total accidents during the three year period, but about 23.5% of all fatal or serious injuries. In a previous study period, 1945 through 1948, stall/spin accidents accounted for about 48% of all fatal general aviation accidents. This significant reduction in the rate of spin-related accidents and fatalities followed the adoption of CAR amendment 20-3 on June 15, 1949, deleting the spin recovery demonstration from pilot testing. The reasons for the reduction in stall/spin fatality rates are not entirely clear, but an emphasis on stall-recognition in the training syllabus and the adoption of stall-warning devices are certainly major factors. A third factor is the more forgiving nature of most modern general aviation aircraft, which are characterized by relatively modest rudder authority and wings with good aileron control at the stall. The NTSB studies confirm the lower accident rates of the new designs when compared to older stall/spin era aircraft.

A significant factor in stall/spin accidents is the fact that approximately 90% occur during takeoff, landing or as a consequence of low-altitude operations. Thus, recovery before impact is difficult, and probably unlikely, even for spin-qualified pilots and aircraft designed for rapid spin recovery. Clearly, the greatest benefit would be obtained by aircraft with spin resistant and forgiving stall characteristics.

The present NASA study of the spin characteristics of various craft configurations will provide useful information. Logic and accident statistics would suggest that the program be expanded to emphasize a study of stall-resistant features and design approaches that will reduce the likelihood of incipient spins.

A-3 LEADING EDGE SLATS

First developed nearly 60 years ago, leading edge slats increase both maximum lift coefficient and the angle-of-attack at the stall. They may be fixed, automatic, or adjustable. Fixed slats have the merit of

simplicity, but cause increased drag at low angle-of-attack (cruise) conditions. This creates no significant problem for certain classes of aircraft, such as ag planes, for which simplicity is more important than a small reduction in top speed. In other applications, automatic and adjustable slats provide low speed benefits without high speed penalities. Slats may also be used to provide stall-proof characteristics without sacrificing low speed performance. By limiting elevator authority, it is possible to maintain relatively large stall margins while actually reducing landing speeds as compared to similar aircraft without leading edge slats.

The aerodynamic characteristics of slats have been well developed. Simple and reliable mechanical control systems may require further work.

A.4 TAILORED AIRFOILS

Advanced computational methods have made it possible to predict the pressure distribution over airfoil sections and, at least to a limited extent, to tailor them for specific applications. New sections useful for general aviation have already been developed for both the high and low speed ends of the spectrum using these methods. Some of the newer business jets have taken advantage of the high-speed drag reduction of the NASA transonic sections and a few recent designs at the lower end of the performance range have incorporated NASA GAW sections.

The activity in airfoil development and analysis has increased radically in the past few years. The results will be of benefit to all segments of aircraft design. It would be unrealistic, however, to expect any major performance improvements for general aviation aircraft operating at speeds below M = 0.6.

A-5 CANARD CONFIGURATION

Canard or tail-first aircraft have a long and distinguished history, the earliest successful proponents being the Wright brothers. Since World War II, there has been a resurgence of interest in the canard, starting with missiles, progressing through fighter development (Saab AJ 37 Viggen) and continuing with the imaginative and successful home-built designs of Bert Rutan. A major advantage of the canard is that

its balancing tail loads add to rather than subtract from wing lift. Pitch response is also more direct. From an aerodynamics standpoint, there appears to be no major disadvantage to the canard configuration.

From a design standpoint, the canard can be thought of as merely one of a number of alternative aircraft layouts. For certain applications, it permits the designer to arrange major weight items in a more efficient manner. On the other hand, it does not appear that any large performance advantage will result directly from the use of tail-first designs. The availability of more general design information on canards would be helpful, and would give the designer a wider set of options in selecting new aircraft configurations.

A-6 WINGLETS

Winglets tend to reduce tip vorticity, increase the effective wing span, and thereby reduce the induced drag. It appears that the same effect can be achieved by extending the wingspan by an amount somewhat less than the height of the winglets. If this is the case, the major application would seem to be in improving the performance of existing aircraft for which it is inconvenient to increase the wing span. It is also possible that winglets will impose slightly lower bending moments on the wing for a given reduction in induced drag. From a safety standpoint, the effect of winglets on roll-off in yawed or unsymmetrical stalls would seem to require further investigation.

On balance, the benefit of winglets to most classes of general aviation aircraft is not clear. Further tests may resolve some of the major questions.

A-7 THRUST/DRAG CONTROL

The use of spoilers or drag brakes to control descent angle has been shown to improve the landing performance of both students and experienced pilots. When coupled with the throttle in a combined thrust/drag lever, the spoiler control can provide a continuous range of flight angles from maximum rate-of-climb to descent angles as steep as eighteen degrees. The combined control reduces the pilot work load, expands the range of positions from which a successful flare and touchdown can be made, shortens the landing run, and provides rapid clean-up for go-arounds.

The design of spoiler systems with acceptable hinge moments may require further research. Also the effect of spoilers in the stall and spin regimes should be investigated.

A-8 POSITIVE SPIRAL STABILITY

Pilot disorientation in IFR conditions continues to take its toll. An attractive solution to the problem, and one that is often suggested, is to improve the inherent spiral stability of general aviation aircraft. Unfortunately, attempts to accomplish this through aerodynamic design have not been successful in the past and are not likely to be notably successful in the future. The side effects of design for spiral stability are generally adverse, and include Dutch roll and unharmonized control forces. Even more important, the stability forces avialable are so small that even minor unbalances, as from unsymmetrical fuel flow or uneven loading conditions, can negate the inherent stability effects.

Since the potential benefits of inherent spiral stability are large, however, continued research in this area is probably justified. In the meantime, gyroscopically-controlled autopilots are a well-accepted alternative, but tend to be expensive and are subject to failure. An automatic and low-cost wing-leveler that does not depend on auxiliary power would be extremely valuable to the general aviation community.

B. POWERPLANT

B-1 SMALL LOW-COST TURBINES

Turbine engines have not succeded in penetrating markets in which up-to-date reciprocating engines are available. They have dominated the general aviation market above 450 hp (336 kw), however, because there are no modern reciprocating engines in that power range. Cost is a major disadvantage for turbines; fuel efficiency another. Significant improvements in one or both would make it possible to take advantage of the turbine's attractive features (smoothness, light weight, high TBO) in a wider range of general aviation aircraft. The NASA General Aviation Turbine Engine (GATE) program is aimed at developing an effective

technology program for turboshaft and turbofan engines of less than 600 hp (450 kw) and 1500 pounds (680 kg) thrust.

Unfortunately, the problem of reducing both cost and fuel consumption has strong Catch-22 overtones. Reducing specific fuel consumption generally requires more complex design or more exotic materials, both of which tend to increase cost. The converse is equally true. On the basis of present evidence, there seems to be very little liklihood of small turbines competing effectively with reciprocating or rotary engines in the near term, except for specialized applications. A major breakthrough in metal/ceramic parts fabrication could reduce costs and make turbine engines more competitive.

B-2 TURBOCHARGING

Turbocharging is having a resurgence throughout the range of general aviation aircraft. This trend appears to be well justified, since turbocharging increases cruise speed and climb, improves fuel efficiency, and aids in operations from high and hot airports. The recent development of automatic control systems (e.g. fixed waste gate control systems) removes the potential for overboost and misadjustment by careless or unskilled pilots.

B-3 INCREASED TBO

The suggested overhaul life of general aviation reciprocating engines ranges from 1200 hours to 2000 hours. The latter figure represents an average service life of about 300,000 miles. Although this is remarkably good performance by comparison with almost any other form of transportation, there is evidence that safe overhaul life can be extended through suitable operational procedures and modern testing techniques. Specifically, scheduled maintenance and rigorous engine condition tests can justify continued operation until there is evidence of an incipient failure. Compression checks, oil consumption logs, spark plug examination and oil analysis can provide an early warning of failure, adequate to insure timely removal and overhaul.

An attempt on the part of engine manufacturers, operators, and the FAA to define conditions under which extended operational life is acceptable would be valuable to general aviation owners and operators.

(Note: On March 18, 1978, the British Civil Aviation Authority issued Airworthiness Notice No. 35, which allows engines in aircraft weighing up to 6000 pounds (2730 kg) and not used for public transport to "continue in service indefinitely". This is a major change from the CAA's previous insistence on a fixed overhaul life for all reciprocating engines).

B-4 WANKEL ENGINE

The Wankel engine has had its ups and downs over the past 10 years. Once hailed as the internal combustion engine of the future, it has suffered from mechanical seal problems and from relatively poor specific fuel consumption. As a result of intensive development, many of these problems appear to have been overcome, and the Wankel engine is reentering the automotive market. It may be an appropriate time to reconsider the Wankel for general aviation aircraft.

Recent Curtiss-Wright RC-75 tests under the auspices of NASA indicate that competitive specific fuel consumptions can be achieved and that combustion seal wear rates will permit extended service life. The installed weight will be appreciably less than currently available engines. Liquid cooling is a disadvantage from the standpoint of reliability, but has the potential for reducing the cooling drag of the engine. Since the Wankel engine is smaller than equivalent reciprocating engines, it permits more flexibility and easier integration into the overall aircraft design.

B-5 AUTO ENGINE CONVERSIONS

Converted auto engines have been used in aircraft since the earliest days of flight. Their promise has been low cost at some sacrifice in weight and reliability. Over the years, reality has not lived up to the promise. A major stumbling block has been the need for FAA certification and manufacturing surveillance. Auto engines also require major changes to adapt them for propeller drive and to operate at various altitudes and in a variety of attitudes. Once approved, the engines must be built to a fixed specification. Since automobile manufacturers are free to change specifications at will, and often do, the resulting certification problems have kept automobile engines out of the mainstream of general aviation development.

In the homebuilt field, automobile engines, particularly the Volkswagen series, have been used successfully, since FAA approval is not required. Some high-powered V-8 conversions appear to have potential for specialized applications, as in the case of agricultural aircraft.

B-6 DIESEL ENGINES

Diesel engines have had limited use in aircraft in the past, but there have been no production applications since World War II. Current interest in the diesel is based on its fuel efficiency, its use of lower grade fuels, and its generally low emissions. Diesels tend to be heavier than their gasoline-powered counterparts.

In view of the time and cost required to develop a new engine for aircraft use, the likelihood of a general aviation diesel in the near future is remote. The current activity in the automotive diesel field will undoubtedly give some impetus to studies of aircraft diesels, however, and continuing research programs are probably justified.

B-7 STRATIFIED CHARGE ENGINES

Stratified charge engines (including pre-chamber designs) are capable of meeting current auto emission requirements without the need for rebreathing or calalytic converters. Even though the EPA has recently decided against imposing emission requirements on general aviation engines, the possibility of future limits cannot be ignored. Thus, the merits of stratified charge designs would seem to justify their consideration for new or modified aircraft engines. The problems of adopting this technology to the special needs (including FAA certification) of aviation may prove difficult, but Honda, the principal exponent of pre-chamber design, has demonstrated the conversion of standard U.S. auto engines to the stratified charge configuration with relatively simple modifications.

B-8 LIQUID COOLING

It has been argued that a liquid-cooled aircraft engine makes about as much sense as an air-cooled submarine engine. The analogy may be extreme, but it rests on a strong logical base. Nevertheless, there is

likely to be an increased interest in liquid cooling for an equally persuasive set of reasons. Liquid cooled engines are quieter because of the surrounding coolant jackets. They are less likely to have hot spots and can therefore run with leaner mixtures and be designed with closer tolerances. Thermal shock during descent is essentially eliminated and cooling drag could be virtually eliminated under certain operating conditions. Cabin heating with engine coolant would also provide an improvement in safety over exhaust heaters.

Balancing these advantages are the radiator, pipes, hoses and pumps, all a potential source of maintenace and safety problems. Since several new liquid-cooled engine types are being actively considered for general aviation aircraft, increased R & D in this area would seem to be justified.

B-9 REDUCED COOLING DRAG

The cooling drag for reciprocating engines can represent a major part of the total airplane drag. Studies have shown that large reductions in cooling drag are possible for conventional air-cooled engines. An impressive reduction was accomplished recently in the clean-up of the Mooney 201. Since heat energy is being rejected to the airstream, it seems possible that careful design could actually result in the production of net thrust. Such a development has obvious advantages for all classes of general aviation aircraft.

Liquid-cooled engines appear to be particularly attractive for such a development since the heat exchanger ducts lend themselves readily to optimum shaping.

B-10 INTEGRATED MIXTURE & SPARK CONTROL

Interactive electronic control systems have great potential for improving fuel economy and lowering emissions. Sensors monitor crankshaft position, throttle position, manifold pressure and temperature, barometric pressure, and cylinder head temperature. A solid state module with a digital microprocessor uses this information to calculate spark advance and mixture setting. The result is a precisely controlled air/fuel ratio and optimum spark timing for all conditions of engine operation, from

idle to take-off power and from sea level to maximum altitude. The obvious merits of this system are that it improves the specific fuel consumption of existing engines, reduces pollutants in the exhaust, and takes advantage of new low-cost high-performance integrated circuits.

Such units are already in use in U.S. passenger cars and will be installed in more models for 1979. The development and production experience obtained in these applications should facilitate their introduction into new and existing general aviation engines.

B-11 IMPROVED MUFFLERS

Since the major powerplant noise is generated by the propeller(s), efficient mufflers for aircraft have received relatively little attention in the past. New noise regulations and the expected reduction in propeller noise levels will put more pressure on muffler development. The problem of reducing exhaust noise by 10-15 dBA without significant increase in intake restriction or exhaust back pressure will be a real challenge. Effective mufflers could reduce the output of normally-operated engines by 2% to 4%. The reduction for turbocharged engines would be somewhat less. Engine compartment space may also be a problem, since larger mufflers may be required to bring about major reductions in exhaust noise. Finally the weight penalties of effective mufflers will have an adverse effect on aircraft performance.

At the present time, it appears that a sufficient analytic basis exists for the development of effective aircraft mufflers.

B-12 CARBURETOR ICE DETECTION

The continuous use of carburetor heat in potential icing conditions reduces performance and increases fuel consumption. A reliable and inexpensive ice detector makes it possible to add heat only when ice is actually forming in the carburetor throat. It also warns unobservant pilots of danger. The fact that such units are presently available and yet have not found general acceptance would seem to indicate that most pilots do not perceive the problem to be a serious one. In this connection,

NTSB statistics show that carburetor ice-related accidents represent only 1.0% of the total U.S. general aviation accidents. Since no safety device is likely to reduce accidents from a given cause to absolute zero, the apparent lack of interest is not entirely unjustified. Recent studies in Canada (where a much higher percentage of accidents is attributed to carburetor ice) seem to show that carburetor ice can be virtually eliminated by coating the throttle shaft and carburetor throat with Teflon.

Until all aircraft are equipped with fuel-injection engines, carburetor ice detectors or ice suppressants could make a valuable contribution to the safety of general aviation aircraft.

B-13 CRASH RESISTANT FUEL CELLS

In the late 1940's, the CAA initiated a study of post-crash fires. Further tests were conducted during the 1950's and 1960's primarily with helicopters under the auspices of the U.S. Army. The result was a military specification for crashworthy fuel tanks (MIL-T-27422B) and, starting in 1970, the installation of fuel systems meeting this specification in a variety of military helicopters. Crash statistics since that time have confirmed their value in reducing the frequency of post-crash fires and thermal casualties. The application of this technology to general aviation is not clear. The current military specification is considered to be unnecessarily severe for FAR 23 aircraft with respect to tank size (90 gal drop test volume) and impact velocity (65 ft drop height). Sample general aviation installations to these specifications have resulted in excessive weight penalties and some reduction in fuel capacity. Costs are also unacceptably high. The installed cost of a certificated range-extension fuel tank for helicopters with a fuel capacity of 35 gallons is nearly $10,000.

Recent tests at FAA-NAFEC showed that single-ply bladder tanks designed for crash resistance could survive crash simulations at velocities up to 95 feet-per-second.

Additional development studies are needed to establish a crashworthy fuel tank design goal for general aviation aircraft. In the meantime, impact-resistant tanks similar to those used in the NAFEC tests, or tanks made from such plastics as high density polyethylene could provide useful benefits at moderate costs.

B-14 ADVANCED PROPELLER DESIGN

There are four major areas in which propeller design might be improved; new airfoils, new blade shapes, composite construction, and better propeller/airframe integration. Despite some fairly optimistic projections, the potential increase in efficiency from advanced airfoils appears to be on the order of one percent. If further research confirms this figure, there is little reason to expect much improvement in aircraft performance from this source alone. Better integration of the propeller and airframe to reduce interference effects, on the other hand, could show increases in propulsive efficiency on the order of two or three percent. The combination of the two would provide a useful increment.

Composite construction has the potential for reducing the cost and weight of propeller blades and increasing their fatigue life. These potentials are largely speculative at the present time since they have not been verified by practical demonstrations. Current blade failure rate on reciprocating engines is approximately one per million flight hours.

Finally, the propeller represents the major source of noise on the airplane. Configuration changes such as swept tips may reduce noise levels by 5 to 10 db. If this can be accomplished without loss in performance, it will have gone a long way toward meeting current and future noise requirements.

Reciprocating/rotary/turboprop engines are likely to be with us for a long time. Propeller research in all four of the above areas would seem to be well justified.

B-15 DUCTED PROPULSORS

The ducted propulsor is one solution to the increasingly stringent noise restrictions being imposed on all aircraft. Since approximately 85% of powerplant noise is the result of propeller tips operating near sonic speeds, an obvious solution is to reduce blade tip speed. Reducing propeller diameter can be effective, but requires multiple blades to maintain performance. NASA is currently looking into this option for large high-speed transports, but the potential for general aviation aircraft may be limited. Lower engine rpm is also effective, but requires gearing and either larger diameter or more blades to maintain performance. Larger

diameters are often a problem because of airframe interference or ground clearance.

The ducted propulsor combines a small diameter, multi-blade rotor with a fixed shroud. Both features tend to reduce the noise level. The shroud provides good static thrust at some penalty in high-speed drag. The rotor-shroud combination are also relatively heavy and expensive.

It is evident that the adoption of multi-blade or ducted propulsors will depend on the severity of future noise regulations. If engine mufflers and swept propeller tips, for example are sufficient to meet future reductions, then the more complex solutions may not be required.

C. STRUCTURES, MATERIALS & FABRICATION

C-1 CRASH-RESISTANT CABIN STRUCTURE

Surviability is enhanced if the approximate shape and volume of the cabin structure can be retained throughout a crash sequence. A major problem in designing for crash impact has been the lack of information on the dynamic forces imposed on the structure during representative crash sequences. Another has been the difficulty in accounting for the elasto-plastic response of various structural elements, since the failure modes are likely to vary with the rate of load application.

Current research being carried out by NASA, FAA and government contractors will provide valuable insights into both problems and provide a basis for good crashworthy design without serious weight or functional penalties. Advanced analytic techniques, such as finite element anlyasis, will make it possible to consider complex failure modes at an early stage in the design process.

C-2 ADVANCED ANALYTIC TECHNIQUES

Advanced analytic methods are making it possible to consider increasingly broad sets of conditions during the design and certification of general aviation aircraft. This is particularly true in the areas of structural integrity, flutter, aerodynamic optimization and failure analysis.

New aircraft designs will benefit in performance, safety and payload as these new techniques come into common usage.

Finite element analysis is having a revolutionary effect on the optimization of aircraft structures. Methods for calculating pressure distribution over arbitrary shapes have already been mentioned. The development of simplified design methods based on these techniques will enable the general aviation industry to realize the full potential of the continuing computer revolution.

C-3 HIGH-STRENGTH, HIGH-MODULUS FIBERS

The use of high-strength, high-modulus fibers in airframe design has been the subject of optimistic projections for a long time. When used in ways that take advantage of their remarkable properties, they can save weight and improve fatigue life. Unidirectional fibers are particularly attractive for spar caps, stiffeners, and landing gear legs. Fiber reinforced plastic (FRP) processes also make it possible to mold complex shapes for secondary structure, such as cowlings, doors, and wing tips.

Unfortunately, a large part of general aviation structures consist of skins, frames and shear webs, which are not suitable for unidirectional layups. Shear panels, for example, require a quasi-isotropic layup that reduces the effective modulus of the fibers by a factor of four or five. The resulting panels are nearly as heavy, and in some cases heavier than equivalent aluminum panels.

Considering the high cost of boron and graphite fibers ($125/pound and $35/pound respectively), the prospects for application to the general aviation market seem very limited. Kevlar fibers on the other hand, have properties that lie between glass and graphite, are relatively inexpensive (less than $10/pound), and have the potential for further cost reduction through volume production. Combinations of glass and Kevlar fibers appear to attractive for a variety of general aviation applications.

C-4 MATCHED-DIE FIBER REINFORCED PLASTIC

Of all the methods for using composite materials in general aviation aircraft, matched-die FRP appears to have the greatest potential for reducing costs. It is presently used in a variety of consumer products,

from bakery trays to automobile bodies. It features fast cycle time, semi-automated processes, and good control of thickness distribution and glass-to-resin ratios. Although it does not have the structural strength of continuous filament layups, it provides good stiffness and an excellent surface finish. Since many airframe parts are designed by stiffness considerations rather than by strength, the lack of specific strength may not be serious, particularly if new approaches to design are used.

The cost of matched-die tooling can be prohibitive for low-volume production, but many general aviation aircraft are now being built in sufficient volume to take advantage of this well-established technique.

C-5 SANDWICH PANELS

Commercially available sandwich panels have been used for secondary structure in a variety of general aviation designs. They would appear to have excellent potential for use as primary structure. Specifically, the all-aluminum panels made with a thin crushed layer of aluminum honeycomb, adhesively bonded between facings of 2024-T3 aluminum alloy are particularly attractive. Their weight is approximately one-half that of solid aluminum panels, but their stiffness is approximately the same. As external panels, they would provide an aerodynamically smooth surface with a minimum of internal structure. The difficulty in forming small radii will be one limitation to the ways in which such panels can be used.

In-house fabrication of conventional sandwich airframe parts tend to be too expensive for most applications. Quality control and field maintenance are also problems that will tend to reduce their potential for use in general aviation design.

C-6 STRUCTURAL FOAM

Two types of structural foam are of interest for aircraft construction. The first of these, structural foam as used in the consumer products industry, may be defined as a plastic product having integral skins, a cellular core, and a relatively high strength-to-weight ratio by commercial standards. It includes both thermoplastic and thermoset polymers and can be formed in a wide range of densities. Suitable for high production rates, it is used to make such items as furniture, tote boxes and auto body

panels. Capital costs are high, involving injection molding machines and metal dies. The use of this type of foam for secondary structural applications (doors, cabin enclosures, etc.) is a chicken-and-egg sort of thing for general aviation, involving a pre-commitment to high production rates in order to obtain low costs - or vice versa.

The second type of foam construction uses low density, rigid foam as a core material over which fiberglass cloth is bonded with polyester or epoxy resin. This process has been widely used for amateur-built and specialty aircraft. It allows the use of relatively complex shapes without tooling or molds, provides excellent surface finish, and is lightweight. It has not yet been used as primary structure in a powered high-production, FAA-certified general aviation aircraft. Its potential appears to be high, but it may require a degree of craftsmanship that is incompatible with mass production. A combination of shaped foam and exterior molds may help to solve the craftsmanship problem.

C-7 CHEM MILLING

Chemical milling was developed in the early 1950's to reduce the weight of large welded aluminum booster tanks. It has been used extensively in missiles and spacecraft, military aircraft and large transports. In all of these applications, the specific costs of the completed vehicle are in the range of $100 per pound or more. The value of a pound saved may be even greater. With few exceptions, chemical milling has not been found to be cost effective for general aviation aircraft. Its use will probably expand somewhat among the largest and most expensive general aviation business aircraft, but chemical milling is not likely to have much influence on the design of smaller general aviation aircraft.

C-8 METAL BONDING

Although adhesives have been used in metal aircraft construction for about 40 years, durability continues to be a problem. Field maintenance and repair are also more difficult and less reliable than for mechanical fasteners. These deficiencies have limited the use of metal bonding for primary structure, even though the potential improvements in cost, weight, and aerodynamic cleanliness are attractive.

The U.S. Air Force has a current program to develop solutions to

these problems and to set standards for the analysis, design, and inspection of bonded structures. Known as PABST (Primary Adhesively Bonded Structure Technology), it has concentrated on conventional 2000 and 7000 series aluminum alloys and film adhesives that cure at about 250°F.

Automakers and several military aircraft manufacturers are also experimenting with a combination of spot welding and adhesive bonding known as weldbonding. Both programs should go a long way toward assuring general aircraft manufacturers that the advantages of adhesive bonding can be realized without concern for the structural integrity of aircraft that may be in use for 30 or 40 years.

D. AVIONICS

D-1 MICROMINIATURIZATION

The microminaturization of electronic circuits is implicit in nearly all the potential improvements in avionics and many of those in the field of instrumentation. The trend toward higher performance densities has been the result of agressive development by avionics manufacturers and the electronics industry in general. The trend is likely to continue and, along with active competition, should provide significant reductions in cost for current units and bring more sophisticated units into the general aviation field.

The effect of these changes on the general aviation industry is difficult to assess. Navigation procedures are not likely to change appreciably, at least until the NAVSTAR system is operational. By enabling the automation of more navigation and control functions, however, advanced electronic equipment will open IFR flying to a broader range of general aviation pilots.

D-2 CRT NAVIGATION DISPLAYS

Cathode Ray Tube (CRT) navigation displays have been a technical goal since shortly after World War II. Real time position displays superimposed on a terrain feature map of one kind or another would greatly simplify navigation and open up safe IFR operations to a considerably larger group

of pilots. The potential is great and the technical tools are generally available, thanks to the impressive developments of the electronics industry in recent years. Since first units will be very expensive, their use is not likely to have an effect on general aviation operations in the immediate future.

Based on potential alone, such displays deserve strong R & D support from all segments of the aviation community.

D-3 LOW-COST PROGRAMMED NAVIGATION

As with many artifacts of the computer age, the future of computer-autopilot programmed navigation may depend more on pilot confidence than on technical merit. It is possible to trust automated equipment for enroute navigation, for example, without being fully at ease in marginal conditions or for fully-coupled ILS approaches. The ultimate level of use for programmed navigation will thus depend on the development of low cost and reliable systems (technically feasible today) and on a rising confidence level on the part of general aviation pilots.

The increasing use of computers for control in business, industry, and transportation may help both in reducing costs and raising confidence levels.

D-4 NAVSTAR

There are presently six navigation systems operated by the government; Loran A., Loran C, Omega, VOR-DME, ADF and ILS. They will soon be joined by a seventh, NavStar, the Defense Department's navigation satellite system. NavStar is also GAO's candidate to replace most of the existing navigation aids. The agency has strongly recommended early adoption of the system for all users. Although there are benefits to military and air transport users, NavStar application to general aviation is a subject of growing controversy. On the positive side, it provides a high degree of accuracy, is relatively unaffected by atmospheric and ionospheric conditions, and combines the functions of VOR-DME and an area navigation computer. On the negative side, the receiver is more complex and therefore more expensive than VOR-based units. Also, an interval of 5 to 8 minutes is required after turn-on to obtain the first position fix, and the pilot must set in the coordinates of his point of departure, his

destination and any waypoints to obtain VOR-type information. The additional workload and the opportunity to make mistakes is a major concern, particularly for single-pilot operation. Military control of the system and the problem of worldwide acceptance are two other inhibiting factors.

Schedule slippages and cost overruns in the Defense Department's current NavStar development program are likely to blunt the GAO's push for universal adoption. The current ICAO protection date for ILS is 1995. The Vortac protection date is 1985. The latter is likely to be extended by ICAO as the debate warms up.

At the present time, it is difficult to see NavStar as a positive influence on general aviation, particularly for the smaller aircraft that represent a majority of the existing fleet.

D-5 SUPPRESSED ANTENNAS

Suppressed or flush-type antennas can provide some useful improvement in the performance of business jets and turboprops, but only small improvements for aircraft at the lower end of the speed scale. Since flush antennas are more expensive and less efficient (in terms of radiated energy) their use in the smaller general aviation does not seem likely in the immediate future.

Continued development of suppressed antenna systems for all classes of aircraft is justified by the need for aerodynamic clean-up, a major challenge to designers in the years ahead.

D-6 LOW COST WEATHER DETECTORS

Low cost and reliable weather detectors extend the operational envelopes of single engine and light twin general aviation aircraft. Suitable models are already available, although the $7,000-$8,000 installed costs will tend to limit their use. The Ryan "Stormscope" records lightning discharges in thunderstorms. The Bendic RDR-160, a conventional radar set, has been mounted in wing pods, and the RCA Primus 20 in the nose of a single aircraft. The RCA Weatherscout can fit within the normal contour of a wing leading edge.

These and more advanced units will clearly influence the design of more sophisticated aircraft at the lower end of the price scale.

E. INSTRUMENTATION

E-1 COORDINATED INSTRUMENT DISPLAYS

"The whole information system in an aircraft instrument panel is an abomination, with zillions of fragmented bits of information the pilot must synthesize from abstract notions".* It is no secret that our present instrument panel layouts are the result of piece-by-piece development of instruments prior to World War II and the ready availability of war surplus instruments. Flight director systems greatly simplify pilot tasks, but are expensive, some costing as much as a complete aircraft at the low end of the general aviation scale. What is needed is a new look at the instrument panels of general aviation aircraft with a view to simplifying the entire display system and making it visually representative of the functions to be carried out by the pilot.

Such units have been demonstrated in the past, as for example, the FAA-funded Peripheral Vision Flight Display system developed by Howard Hasbrook. The earlier Kaiser navigation display presented the pilot with the visual equivalent of driving along a highway. The growing capability of the electronics industry should allow such concepts to be explored in an entirely new way and with reasonable hope of bringing them to market at reasonable cost and with a high degree of reliability.

E-2 ANNUNCIATORS (FAILURE-WARNING/CHECK-LIST)

Failure warning and check list annunciators are available for transport category aircraft and for business jets and turboprops. They are generally sophisticated and expensive. Low cost annunciators with limited functions, based on a combination of aircraft and automotive technology, could be available within a few years. By reducing workload and giving timely failure warning, they would improve the safety of today's increasingly complex small general aviation aircraft.

E-3 ON-BOARD PERFORMANCE CALCULATORS

A pilot information system that computes and displays operational

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* From letter received by the author

data is now possible at relatively low cost. Based on automotive production economies, the system could also sample and display condition information for powerplant and airframe systems. Digital displays would provide answers to specific questions, thereby reducing the amount of panel space dedicated to information needed only infrequently as, for example, exhaust gas temperatures. The variety of possible displays is limited only by the availability of low-cost and reliable sensors.

The use of time-shared multiplexing could reduce the wiring harness requirements for data transmission from the sensors and thus reduce system complexity and weight. Such multiplexing systems are now used in military transport aircraft, industrial processes, and have been proposed for transit busses. The technology is clearly "in the air" for high volume production.

F. AIRFRAME & SYSTEM DESIGN

F-1 IMPROVED FIREPROOFING

The self-extinguishing requirements for FAR 25 interior materials are clearly defined in the regulations. The FAR 23 requirements are less specific, relying indirectly on FSS Release #453. A better definition of fire resistance for FAR 23 aircraft would encourage manufacturers to take advantage of recent developments in flame retardants and in the use of flame-retardant materials.

F-2 ICE-SHEDDING SURFACES

Anti-icing equipment that is inexpensive, dependable and does not compromise surface aerodynamics would be a major improvement for general aviation aircraft intended for IFR operations. Rubber boots on the leading edge are inconsistent with aerodynamic cleanliness, are relatively expensive, and represent a major maintenance problem. Heated leading edges are better aerodynamically, but also involve penalties in weight, cost, and maintenance. A promising alternative is the use of ice-shedding or icephobic materials for leading edge construction or coatings. Olefin plastics have already been used for this purpose on helicopter rotor blades.

Research into the capability of such materials would be helpful in defining the limits of their use. Positive results would provide anti-ice protection at reasonable cost and weight and with little or no penalty in aerodynamic performance.

F-3 OXYGEN WITHOUT MASKS

Oxygen masks are necessary for high altitude flight without pressurization. They are also inconvenient, uncomfortable, and unacceptable to some individuals. The availability of a suitable alternative for medium altitude flying (up to 18,000 feet) would allow pilots (and designers) to take advantage of the speed and fuel efficiency of turbocharging without the weight and cost penalities of cabin pressurization. One possibility is the nasal canula, recently introduced for aviation use. Further testing of this and other solutions to the oxygen problem could provide satisfactory operating conditions and safeguards for flight at moderate altitudes.

A successful solution to this problem would accelerate the trend toward turbocharging and the use of higher and more efficient cruise altitudes.

G. HUMAN FACTORS & OPERATIONS

G-1 CONTROLS STANDARDIZATION

With few exceptions, each airplane model represents a new set of controls for the pilot to master. Unless he flies the same airplane regularly, his instinctive responses to an emergency may be wrong or delayed. Although a certain amount of standardization has been imposed by the FAA regulations, further standardization of operations and location would clearly contribute to safety. There is always the danger, of course, that standardization by regulation will tend to stifle inovation and the development of new approaches to old problems. Any trend toward standardization must insure that an open attitude is maintained toward innovations such as a side-stick controls, integrated power levers, and thrust/drag control systems.

G-2 IMPROVED PASSENGER RESTRAINT

The value of effective passenger restraint on survival has been clearly demonstrated. The design of adequate restraint systems, particularly since the introduction of the inertia reel, is also well advanced. The problems of comfort, convenience and user acceptance are still unresolved. Since the effectiveness of any restraint system depends on acceptance, it seems that the design goal must be to provide the best trade-off between comfort in normal use and restraint in the event of an accident. Thus, the very best restraint systems, as used in military aircraft for example, may not be the most effective for general aviation aircraft.

Continued investigation of such trade-offs would be valuable to the designer and users alike.

G-3 COCKPIT DELETHALIZATION

Along with crash-resistant cabin structure and improved passenger restraint, cockpit delethalization will improve the likelihood of survival in low-speed accidents. The use of energy absorbing foams, the avoidance of hard projecting knobs or instrument panels, and the design of control systems to absorb energy or fail in non-threatening ways can reduce trauma appreciably. Unfortunately, such changes tend to conflict with outside visibility, instrument placement, and control convenience. Many of the technologies required to resolve these problems are available, but the solutions will probably depend on considerable trial and error plus a consensus in the aviation community on the nature of acceptable trade-offs.

All the 46 technologies described above represent new opportunities for improving the safety, performance and utility of general aviation aircraft. Some have already established their value, others require further development and demonstration to encourage their use in general aviation.

Whatever their status, their potential can be realized only when they are carefully integrated into the overall design of a specific airplane. It is the quality of this design synthesis that determines how well they will

perform. Many of the features incorporated in the illustrative designs of Section VIII are as much a matter of design choice as they are of new technologies. The availability of the new technologies does, however, give the designer a wider set of options to work with and thus enables him to come closer to his design objectives.

V NUMERICAL EVALUATION

An attempt has been made in this section to evaluate the leading technologies against a set of consistent criteria. As noted before, the ten selected criteria are far from perfect. There is overlap between safety and reliability. Performance and efficiency have factors in common. Furthermore, any assessment involves subjective judgments about which there are bound to be disagreements. To avoid personal bias as much as possible, a number of knowledgeable people in the general aviation industry were invited to comment on the value and potential of the individual technologies.

The relative importance of the ten criteria is a factor in the evaluation process. It would be difficult, for example, to enforce environmental purity at the expense of safety, a fact acknowledged recently by the Environmental Protection Agency's withdrawal of proposed emission standards for general aviation aircraft. The advisory group also recognized this difference by ranking safety first and environment last. As discussed later, this ranking may be misleading, since society can impose its own set of priorities with little regard to its effect on the aviation community. Noise standards are here to stay, for example, and there is every reason to expect that they will become more stringent with time. Emission standards may be more dormant than dead.

The following definitions of the criteria may help to clarify the way in which they were used for this part of the study. They are given in the order of importance assigned to them in this study.

1. SAFETY - Protection against the danger of injury or loss. Although reliability is a factor, the major considerations are accident prevention and occupant protection in the event of a crash.

2. RELIABILITY - Relative assurance against failure. Complex systems will generally score poorly in this category.

3. PERFORMANCE - Covers the broad range of functions performed by general aviation aircraft. Includes rate-of-climb, descent angle, stall speed, high speed, payload, etc.

4. COST - For the most part, considers only first cost. No attempt has been made to consider life cycle costs. Where operational costs

are obviously affected, this factor has been taken into account.

5. CUSTOMER ACCEPTANCE - A most difficult factor to judge. Since all the technologies considered in this study tend to improve some aspects of general aviation operations, customer acceptance is almost sure to be positive, or at least neutral.

6. EFFICIENCY - A factor that is concerned almost entirely with the ratio between performance and fuel consumption. No attempt has been made to consider raw material use or production efficiency.

7. OPERATIONAL EASE & UTILITY - A portmanteau term combining pilot workload, suitability for specialized tasks, and expansion of the operational envelope.

8. MAINTENANCE - Ruggedness, ease of access and a lack of critical adjustments for proper operation.

9. WEIGHT - Effect on the empty weight of the airplane.

10. ENVIRONMENT - Effect on the external environment, primarily noise and emissions.

The order of importance originally selected for these criteria was slightly different from that given above. The final order is based on the combined rankings of approximately 40 individual judgments. The major difference between the original and the final rankings is the relatively lower rank assigned to WEIGHT by the correspondents. Analysis of the responses showed that this downgrading of the weight factor was reasonably consistent across the board, from designers to researchers to journalists. No changes in the ranking of the criteria occurred after the first 25 responses were tabulated.

Several individuals pointed out that a major problem with applying this type of ranking to all general aviation aircraft is that the priorities for a 100-hp trainer are not likely to be the same as those of a corporate jet. The author is entirely sympathetic to this viewpoint, but feels that a more complex procedure would have been out of place in this preliminary study. A modest check of the sensitivity of the results to changes in the emphasis given to each criterion shows that the conclusions would remain essentially the same.

Since the criteria tended to fall into five pairs in the ranking, the

following weights were assigned for a total of 100 points.

1.	SAFETY	15
2.	RELIABILITY	15
3.	PERFORMANCE	12
4.	COST	12
5.	CUSTOMER ACCEPTANCE	10
6.	EFFICIENCY	10
7.	OPERATIONAL EASE & UTILITY	8
8.	MAINTENANCE	8
9.	WEIGHT	5
10.	ENVIRONMENT	5

The spread from least important to most important is 3:1, and the distribution is symmetrical around the mean.

Technologies were judged against each of the criteria using a scale of +3 to -3, with the positive numbers denoting benefit or improvement, the negative numbers denoting a penalty or worsening. The assignment of a zero value implies either that the technology had no appreciable effect on that particular criterion or that the costs and benefits appeared to balance one another. The product of this number times the weight assigned to the criterion gives a figure of merit for that particular factor. The sum of all ten products gives an overall figure of merit for the technology. The results are shown in Table 2.

In evaluating the technologies, it is important to define the nature of the comparison being made. In the case of ice-shedding surfaces, for example, the comparison could be made either against existing boots, fluid dispensers and heated leading edges, or against a standard airframe with no provisions for anti-icing. The former was selected for this particular comparison, as is apparent from the figures of merit. The distribution of points for each of the technologies tends to clarify the nature of the comparison being made.

Finally, the figures of merit must not be taken as an ultimate judgment. Events and circumstances can change the rankings very considerably. The ducted propulsor is a good example. It is probably the most effective means for reducing the noise level of reciprocating engine-propeller combinations. It is also heavier and more expensive than a conventional propeller and its drag is relatively high at the high speed end of the spectrum. As a

	SAFETY	RELIABILITY	PERFORMANCE	COST	CUSTOMER ACCEPTANCE	EFFICIENCY	OPERATIONAL EASE	MAINTENANCE	WEIGHT	ENVIRONMENT	TOTAL
	15	15	12	12	10	10	8	8	5	5	
A. AERODYNAMICS											
1. Spoilers/Full-Span Flaps	+15		+24		+10	+10			+5		+64
2. Improve Stall/Spin	+45				+10		+16				+71
3. Leading Edge Slats	+45	-15	+12	-12	+10	+10	+ 8	- 8	-10		+40
4. Tailored Airfoils	+15		+12		+10	+10					+47
5. Canard Configuration			+12			+10					+22
6. Winglets			+12	-12	+10	+10		- 8	- 5		+ 7
7. Thrust/Drag Control	+15	-15	+12	-12	+20		+16	- 8	- 5	+ 5	+28
8. Pos. Spiral Stability	+30				+20		+ 8				+58
B. POWERPLANT											
1. Small Lo-Cost Turbines		+15	+36	-36	+20	-10	+ 8		+10		+43
2. Turbocharging	+15		+24	-12	+10	+20		- 8	- 5		+44
3. Increased TBO	+15	+15		+12	+20		+ 8	+16			+86
4. Wankel Engine		+15			+10			+ 8	+10		+43
5. Auto Engine Conversions		-15		+24				+ 8	-10		+ 7
6. Diesel Engines	+15	+15		-12	+10	+10			-10	+ 5	+33
7. Stratified Charge Engines				-12	+10		+ 8			+15	+21
8. Liquid Cooling		-15	+12	-12		+10	- 8	- 8	- 5	+ 5	-21
9. Reduced Cooling Drag			+24		+10	+20			- 5		+49
10. Integrated Mix/Spark			+12	-12		+10				+10	+20
11. Improved Mufflers			-12	-12	+10				- 5	+10	- 9
12. Carb Ice Detection	+30	-15		-12	+20		+ 8	- 8			+23
13. Crash-Resist Fuel Cells	+30			-24	+10			- 8	- 5		+ 3
14. Advanced Prop Design			+12		+10	+10			+ 5		+37
15. Ducted Propulsors			-12	-24	+10	-10		- 8	-10	+15	-39
C. STRUCTURES, MATERIALS, FABRICATION											
1. Crash-Resist Cabin Struct	+45			-12	+10				- 5		+38
2. Advanced Analysis Techniques	+15		+12			+10			+ 5		+42
3. Hi-Strength, Hi-Mod Fibers		-15	+12	-24	+10			- 8	+10		-15
4. Matched-Die FRP			+12	+12	+10			+ 8	- 5		+37
5. Sandwich Panels			+12	+12	+10				- 5		+29
6. Structural Foam		-15	+12		+10				- 5		+ 2
7. Chem Milling				-24					+ 5		-19
8. Metal Bonding		-15	+12	+12	+10	+10		- 8			+21

TABLE 2. Numerical Evaluation of Technologies

	SAFETY	RELIABILITY	PERFORMANCE	COST	CUSTOMER ACCEPTANCE	EFFICIENCY	OPERATIONAL EASE	MAINTENANCE	WEIGHT	ENVIRONMENT	
	15	15	12	12	10	10	8	8	5	5	
D. AVIONICS											
1. Microminiaturization		+15	+12	+12	+10		+ 8	+ 8	+ 5		+70
2. CRT Navigation Displays	+15	-15		-24	+20		+16	- 8	- 5		- 1
3. Lo-Cost Programmed NAV	+15	-15		-12	+20		+16	- 8	- 5		+11
4. NAVSTAR	+ 5	+15		-24			+ 8	- 8			- 4
5. Suppressed Antennas			+12	-12	+10	+10	- 8	- 8	- 5		- 1
6. Lo-Cost Weather Detectors	+15	-15		-24	+10		+16	- 8	- 5		-11
E. INSTRUMENTATION											
1. Coord Instrument Displays	+15			-12	+30		+ 8				+41
2. Annunciators (Fail/Check)	+15			-12	+10		+ 8	- 8			+13
3. On-Board Perf Calculators	+ 5	-15		-12	+20		+ 8	- 8	- 5		- 7
F. AIRFRAME & SYSTEM DESIGN											
1. Improved Fireproofing	+30			-12							+18
2. Ice-Shedding Surfaces	-15	+15	+12	+24	+10	+10		+ 8	+ 5		+69
3. Oxygen w/o Masks					+20		+16				+36
G. HUMAN FACTORS & OPERATIONS											
1. Controls Standarization	+15				+20		+ 8				+43
2. Improved Pass Restraint	+30			-12	+10						+28
3. Cockpit Delethalization	+30				+10		- 8				+32

TABLE 2. Numerical Evaluation of Technologies (cont'd)

result, its figure of merit is low in comparison with all the others listed. Despite this low ranking, it is possible to imagine a situation in which the ducted propulsor could become a major factor in the design of some types of general aviation aircraft. If, for example, strict noise limits are imposed on close-in airports, the ducted propulsor may become one of the few means for complying with the regulations. It may be double attractive for short haul passenger/cargo aircraft, where high cruise speeds are less a factor than the ability to operate from metropolitan airports without distressing the neighbors.

VI RANKING OF TECHNOLOGIES

The numerical evaluation procedure makes it possible to rank the technologies in a general order of merit regardless of category. Table 3 shows the order of the 46 technologies described in the two previous sections of the report. Since the assessments are obviously far from exact, the strict order should not be taken too seriously. It is probably reasonable to speak of high, middle, and low ranges, however, with the technologies in each group having similar potential and priority.

Table 3 also notes which of the technologies has a positive impact on the three leading criteria; safety, performance and cost. Of the total, 22 have a significant impact on safety, 20 on performance, and 8 on cost. Six have no significant impact on any of the three leading criteria.

Eleven of the technologies have a favorable impact on more than one of the three leading criteria. As might be expected, all eleven rank high on the list, with eight in the upper one-third and two in the middle third.

Aerodynamic and powerplant technologies have a higher than average representation in the upper third of the list, whereas avionics technologies have a higher than average distribution in the lower third.

The top-ranking technology, INCREASED TBO, is less a single technology than a combination of small improvements and an expanded use of currently-available diagnostic tools. Changes in FAA inspection procedures to bless extended overhaul life would also be helpful in avoiding the stigma of running beyond "recommended" overhaul times.

The relatively poor showing of avionics is probably due to the fact that increased utility is nearly always balanced by a considerable increase in cost. It is possible, of course, that the cost escalation may be contained by the trend toward all-purpose chips and circuit microminiaturization. There are many requirements, however, that are unique to electronic equipment intended for aircraft use. This factor, along with FAA certification and relatively low production rates, will tend to frustrate efforts to effect major cost reductions.

The whole matter of rankings and priorities deserves a more detailed investigation than is possible in this preliminary effort. The basic

TABLE 3

RANKING OF TECHNOLOGIES

		NUMERICAL SCORE	SAFETY	PERFORMANCE	COST
1.	INCREASED TBO	86	X		X
2.	IMPROVED STALL/SPIN	71	X		
3.	MICROMINIATURIZATION	70		X	X
4.	ICE-SHEDDING SURFACES	69		X	X
5.	SPOILERS/FULL-SPAN FLAPS	64	X	X	
6.	POS. SPIRAL STABILITY	58	X		
7.	REDUCED COOLING DRAG	49		X	
8.	TAILORED AIRFOILS	47	X	X	
9.	TURBOCHARGING	44	X	X	
10.	CONTROLS STANDARIZATION	43	X		
11.	WANKEL ENGINE	43		X	
12.	SMALL LO-COST TURBINES	43	X	X	
13.	ADVANCED ANALYSIS TECHNIQUES	42		X	
14.	LEADING EDGE SLATS	40	X	X	
15.	COORD INSTRUMENT DISPLAYS	41	X		
16.	CRASH-RESIST CABIN STRUCT	38	X		
17.	MATCHED-DIE FRP	37			X
18.	ADVANCED PROP DESIGN	37		X	
19.	OXYGEN W/O MASKS	36			
20.	DIESEL ENGINES	33	X		
21.	COCKPIT DELETHALIZATION	32	X		
22.	SANDWICH PANELS	29		X	X
23.	THRUST/DRAG CONTROL	28	X	X	
24.	IMPROVED PASS RESTRAINT	28	X		
25.	CARB ICE DETECTION	23	X		
26.	CARARD CONFIGURATION	22		X	
27.	METAL BONDING	21		X	X
28.	STRATIFIED CHARGE ENGINES	21			
29.	INTEGRATED MIX/SPARK	20		X	
30.	IMPROVED FIREPROOFING	18	X		
31.	ANNUNCIATORS (FAIL/CHECK)	13	X		
32.	LO-COST PROGRAMMED NAV	11	X		
33.	AUTO ENGINE CONVERSIONS	7			X
34.	WINGLETS	7		X	
35.	CRASH-RESIST FUEL CELLS	3	X		
36.	STRUCTURAL FOAM	2			X
37.	CRT NAVIGATION DISPLAYS	-1	X		
38.	SUPPRESSED ANTENNAS	-1		X	
39.	NAVSTAR	-4			
40.	ON-BOARD PERF CALCULATORS	-7			
41.	IMPROVED MUFFLERS	-9			
42.	LO-COST WEATHER DETECTORS	-11	X		
43.	HI-STRENGTH, HI-MODULUS FIBERS	-15		X	
44.	CHEM MILLING	-19			
45.	LIQUID COOLING	-21		X	
46.	DUCTED PROPULSORS	-39			

procedure does, however, appear to be valid and capable of giving useful insights into the nature of technological trends and the future of general aviation design.

VII SIGNIFICANT TRENDS

Airplane design is carried out in a social and political atmosphere that may influence the direction of new aircraft design as much as the availability of new technologies. The rapid growth of the airline industry in the late 1920's and early 1930's - and the impetus for advanced Boeing and Douglas transports - was due as much to Lindbergh's NY-Paris flight and the expansionist policies of Postmaster General W. R. Brown as it was to the development of the NACA cowl, the controllable pitch propeller, and metal fabrication techniques, all of which were taking place at the same time.

There are notable exceptions. Major technical breakthroughs, such as the turbine engine, tend to drive the system and are thus largely independent of other factors.

No such radical breakthroughs appear likely for general aviation. It thus seems certain that a number of the social and political pressures operating today will play a major role in the direction of general aviation design.

Of the many trends and counter-trends that could influence general aviation design, the following 22 seem to be the most important. Some are contradictory, the influence of others will vary with time, but all are important in considering the future of general aviation design and operations.

1. MULTINATIONALIZATION OF BUSINESS

The rise of the multinational corporation and the decentralization of industries within the United States has created a demand for communication and transportation outside regularly scheduled services. This trend is likely to continue and to provide a strong impetus to the continued growth of general aviation.

2. INVESTMENT TAX CREDIT

Tax benefits on the capital cost of business aircraft have made it possible for corporations to select larger and more sophisticated aircraft than they might otherwise be able to justify. It also encourages more frequent trade-ins and trade-ups. Not to be ignored is the fact that a tax credit tends to legitimize the corporate aircraft as a business tool. Although often questioned, investment tax

credits will probably continue in much the same form as they are today.

3. STATUTORY SPEED LIMITS

The speed limit of 55 mph is under attack in a number of states, but is likely to remain unchanged. The speed benefit of general aviation travel will continue to attract new users and tend to expand current operations.

4. SIMULATOR FLIGHT TRAINING

Already a major factor in transition and proficiency training for airline and corporate pilots, simulators will continue to move down-market. For a constant student pilot population, the need for trainer aircraft will probably be reduced.

5. ELIMINATION OF G. I. PILOT TRAINING

A recurrent issue in the funding of veterans benefits, flight training allowances remain essentially unchanged, although slightly less generous than in the past. As the number of separated servicemen who have been involved in a "shooting war" diminishes, there will be corresponding pressure to reduce G. I. benefits.

6. CONTINUING GROWTH OF GENERAL AVIATION SALES

Increasing sales will mean greater profits and larger cash flows. With a constant percentage of gross revenues committed to R & D, the ability of the general aviation manufacturers to develop new products should increase in the years ahead.

7. INCREASING DEVELOPMENT COSTS

Although the figures are elusive, the costs of R & D for improving existing general aviation products and developing and certifying new products appear to be increasing faster than other parts of the economy. If true, the innovative value of R & D budgets will be reduced.

8. IMPROVED ENGINE & SYSTEM RELIABILITY

Powerplant reliability continues to improve, to the general benefit of safety and the reduction of operational costs. This trend

will continue to encourage the development of more sophisticated single-engine aircraft, leading eventually to the acceptance of single-engine turbofan-powered executive aircraft.

9. MICROMINIATURIZATION

The capability of com-nav systems will be expanded and costs reduced. The result will be more IFR pilots, a trend toward more complex aircraft, increasing pressure on the ATC system, etc., etc.

10. RISING COSTS FOR LOWEST-PRICED AIRCRAFT

The cost of the lowest price airplane on the market today is between two and three times more expensive relative to other consumer products than the lowest priced airplanes of 1950. There are a number of good reasons for this difference, but it clearly has the effect of squeezing the marginal buyer from the new plane market. The used plane market has benefited and will continue to benefit from this trend.

11. GROWTH OF AMATEUR-BUILT MOVEMENT

One of the most dynamic elements of general aviation, the home-building movement, enables enthusiasts to fly at minimum costs and provides an outlet for creative urges. In the past few years it has become a source of aerodynamic and structural innovations that will influence new general aviation design.

12. DEREGULATION OF SCHEDULED AIRLINES

Freedom to change fares and to enter or abandon markets are expected to increase the concentration of the major carriers in the lucrative long-haul markets. The needs of small communities and short-haul routes will be met by commuter-type aircraft, designed and built by the general aviation industry.

13. STRINGENT SAFETY REQUIREMENTS FOR COMMUTER AIRCRAFT

The shift to smaller aircraft for scheduled short-haul routes will generate a demand for certification to FAR 25 standards for all aircraft to be operated in scheduled airline service.

14. AIRPORT AVAILABILITY

Three factors are involved here; the increase in the absolute

number of general aviation airports nationwide, the trend toward longer ground travel time between city centers and major airline airports, and the reduced accessibility of major airports to general aviation aircraft. The first two tend to favor general aviation growth. The last may have little effect so long as alternate metropolitan fields are available.

15. NEED FOR IMPROVED FUEL EFFICIENCY

Already mandated for automobiles, fuel efficiency has become a major factor in the development of new aircraft and engines. The trend will likely accelerate.

16. PRODUCTS LIABILITY LITIGATION

The effect of products liability litigation has been to increase the emphasis on design safety and to boost the price of aircraft. It has also diluted the efforts of engineering managers and discouraged innovation. The net effect is not yet clear, but there is no evidence that the above trends will abate.

17. MORE STRINGENT NOISE REGULATIONS

Environmental pressures will force further reductions in noise levels, particularly for close-in airports.

18. LEGISLATED SAFETY FEATURES

Despite the poor record of congressionally-mandated safety measures (i.e. crash locater beacons), the pressure for specific solutions to perceived problems continues. Some may slip through. They are likely to place increasing cost pressure on the lower end of the general aviation market.

19. PESTICIDE LEGISLATION

A trend away from broad-range and persistent chemicals and toward biological pest control may reduce the expected rate of growth in ag aviation to meet growing demands for food and fiber.

20. USER CHARGES & TAXES

House and Senate subcommittees recently voted to prohibit such charges in fiscal 1979. Pressures both for and against continue.

The present situation, which involves no direct user fees and moderate taxes, may be compromised toward increased costs to the users.

21. INCREASING ATC COMPLEXITY

Higher levels of aircraft traffic and a higher percentage of IFR flight plans will require more sophisticated airborne equipment and will deny increasingly large sections of airspace to aircraft with minimum or no electronic equipment.

22. INCREASING U. S. AFFLUENCE & LEISURE

Average salaries have more than kept pace with inflation and the cost of living. At the same time, the average work-week has steadily decreased. Aircraft designed for sport flying and family transportation are likely to benefit if these two trends continue.

It seems clear that the technologies that are compatible with the above trends will be given preference in the design of new general aviation aircraft. The technologies and the trends are considered together in the next section of the report.

VIII DESIGN SYNTHESIS

The ultimate purpose of this study has been to look into the feasibility of technology demonstration aircraft for general aviation. To do so requires going one step beyond an evaluation of technologies and a catalog of social and political trends. This part of the report describes four designs that could incorporate a number of the most promising technologies, allowing them to be evaluated by the ultimate users, the public and the general aviation industry. It must be said very clearly at this point that the selection is not intended to be inclusive or fully representative. It is merely illustrative, showing some of the opportunities in areas of the marketplace that could benefit from a demonstration program.

The four designs described in this part of the report are all new. An alternative strategy, of course, would be to modify existing general aviation aircraft to incorporate specific new technologies. Since the possible combinations are almost infinite, it seemed best in this limited study to illustrate what might be done by starting with a clean slate. In the long run, it may be more cost effective to demonstrate through modification, although there is much to be said for a fresh start to insure maximum benefit from the new technologies and trends.

The four selected designs are aimed at illustrating ways in which the new technologies could be combined in single airframe/engine combinations. They are:

DESIGN I - Single-engine, high-speed, four-place airplane
DESIGN II - Single-engine, five-place, turbofan airplane
DESIGN III - Single-engine, four-place, crashworthy airplane
DESIGN IV - Twin-engine, quiet, commuter/cargo airplane

Each of the four can incorporate a majority of the most promising technologies and each is generally consistent with the societal trends noted before. Design I and Design III represent relatively modest programs. Design II and Design IV represent more complex and expensive undertakings.

One notable area of the market that deserves attention, but is not represented in this report, is the lowest price or entry airplane. At the present time, the most inexpensive new airplane now available on the U.S. market sells

for about $14,000, four times the cost of the lowest priced new automobile. A modern all-metal trainer is more like five times the cost of an economy car. This ratio is higher than it has ever been since World War II, and results in pricing many prospective private owners out of the market.

It is a situation that no one in the general aviation industry is comfortable with, but the lack of a solution is due neither to neglect or incompetence. The design of a low cost commercial airplane that meets all the necessary safety and utility requirements is possibly the most difficult and intractable of the challenges facing the general aviation industry. Part of the problem is the high cost of FAA-certified engines. Another part is the cost of the production and inspection procedures required to insure the quality of the final product. The most important factor, however, is the limited production base for aircraft. Without a mass market, airplanes must be built with a combination of hand labor and low-production machine processes.

A number of attempts to solve the lowest-price airplane problem were considered in this study, particularly in the way of molded plastic structures and converted automotive engines. None seemed promising enough to report in this section. The author is convinced that attempts to solve this design-production-marketing problem must continue, however. In the meantime, there is an active used-aircraft market for the marginal owner. Even more important, the steady growth in size and quality of the home-building movement has made it possible for anyone with enough desire and a moderate level of manual skills to build his own airplane at low cost.

The application of the 46 technologies to the four selected designs is shown in Table 4. No attempt has been made to rate each application as being either strong or weak, but some aspects of this relationship are covered in the following discussions.

The correlation between the social and political trends and the four designs is shown in Table 5. Again no attempt has been made in the table to characterize the relationship as either strong or weak.

DESIGN I

Design I, shown in Figure 6, is an entirely conventional configuration. Its merit is that it is adaptable to a variety of powerplant installations and can demonstrate a number of advanced technologies at relatively low

TECHNOLOGY	DESIGN I	DESIGN II	DESIGN III	DESIGN IV
A- 1. Spoilers/Full-Span Flaps	X	X	X	X
A- 2. Improve Stall/Spin	X	X	X	X
A- 3. Leading Edge Slats	X	X		X
A- 4. Tailored Airfoils	X	X	X	X
A- 5. Canard Configuration			X	X
A- 6. Winglets		X		X
A- 7. Thrust/Drag Control	X	X		X
A- 8. Pos. Spiral Stability	X		X	
B- 1. Small Lo-Cost Turbines	X	X(1)	X	
B- 2. Turbocharging	X		X	X
B- 3. Increased TBO	X	X	X	X
B- 4. Wankel Engine	X		X	
B- 5. Auto Engine Conversions	X		X	
B- 6. Diesel Engines	X		X	X
B- 7. Stratified Charge Engines	X		X	X
B- 8. Liquid Cooling	X		X	X
B- 9. Reduced Cooling Drag	X		X	X
B-10. Integrated Mix/Spark	X		X	X
B-11. Improved Mufflers	X		X	X
B-12. Carb Ice Detection	X		X	
B-13. Crash-Resist Fuel Cells	X	X	X	X
B-14. Advanced Prop Design	X		X	X
B-15. Ducted Propulsors				X
C- 1. Crash-Resist Cabin Struct	X	X	X	X
C- 2. Advanced Analysis Techniques	X	X	X	X
C- 3. Hi-Strength, Hi-Mod Fibers	X		X	
C- 4. Matched-Die FRP	X		X	X
C- 5. Sandwich Panels	X	X	X	X
C- 6. Structural Foam	X		X	X
C- 7. Chem Milling		X		X
C- 8. Metal Bonding	X	X	X	X

TABLE 4 Correlation Between Technologies and Selected Designs

TECHNOLOGY	DESIGN I	DESIGN II	DESIGN III	DESIGN IV
D- 1. microminiaturization	X	X	X	X
D- 2. CRT Navigation Displays	X	X	X	X
D- 3. Lo-Cost Programmed NAV	X	X	X	X
D- 4. NAVSTAR	X	X	X	X
D- 5. Suppressed Antennas	X	X	X	X
D- 6. Lo-Cost Weather Detectors	X	X	X	X
E- 1. Coord Instrument Displays	X	X	X	X
E- 2. Annunciators (Fail/Check)	X	X	X	X
E- 3. On-Board Perf Calculators	X	X	X	X
F- 1. Improved Fireproofing	X	X	X	X
F- 2. Ice-Shedding Surfaces	X	X	X	X
F- 3. Oxygen w/o Masks	X		X	
G- 1. Controls Standarization	X	X	X	X
G- 2. Improved Pass Restraint	X	X	X	X
G- 3. Cockpit Delethalization	X	X	X	X

(1) In a twin-engine version

TABLE 4. Correlation Between Technologies and Selected Designs (cont'd)

CORRELATION BETWEEN SOCIAL/POLITICAL
TRENDS AND SELECTED DESIGNS

	DESIGN I	DESIGN II	DESIGN III	DESIGN IV
1. Multinationalization of Business	X	X		X
2. Investment Tax Credit		X		X
3. Statutory Speed Limits	X	X	X	X
4. Simulator Flight Training				
5. Reduction in G.I. Pilot Training				
6. Growth of General Aviation Sales	X	X	X	X
7. Increasing Development Costs	X	X	X	X
8. Improved Engine Reliability	X	X	X	X
9. Microminiaturization	X	X	X	X
10. High Costs for Lowest-Priced Acft				
11. Growth of Amateur-Built Movement				
12. Deregulation of Scheduled Airlines				X
13. Safety Req'mts for Commuter Acft				X
14. Airport Availability		X		X
15. Need for Improved Fuel Efficiency	X	X		X
16. Products Liability Litigation	X	X	X	X
17. More Stringent Noise Regulations	X	X	X	X
18. Legislated Safety Features				
19. Pesticide Legislation				
20. User Charges & Taxes		X		
21. Increasing ATC Complexity	X	X	X	X
22. Increasing Affluence & Leisure	x	X	X	X

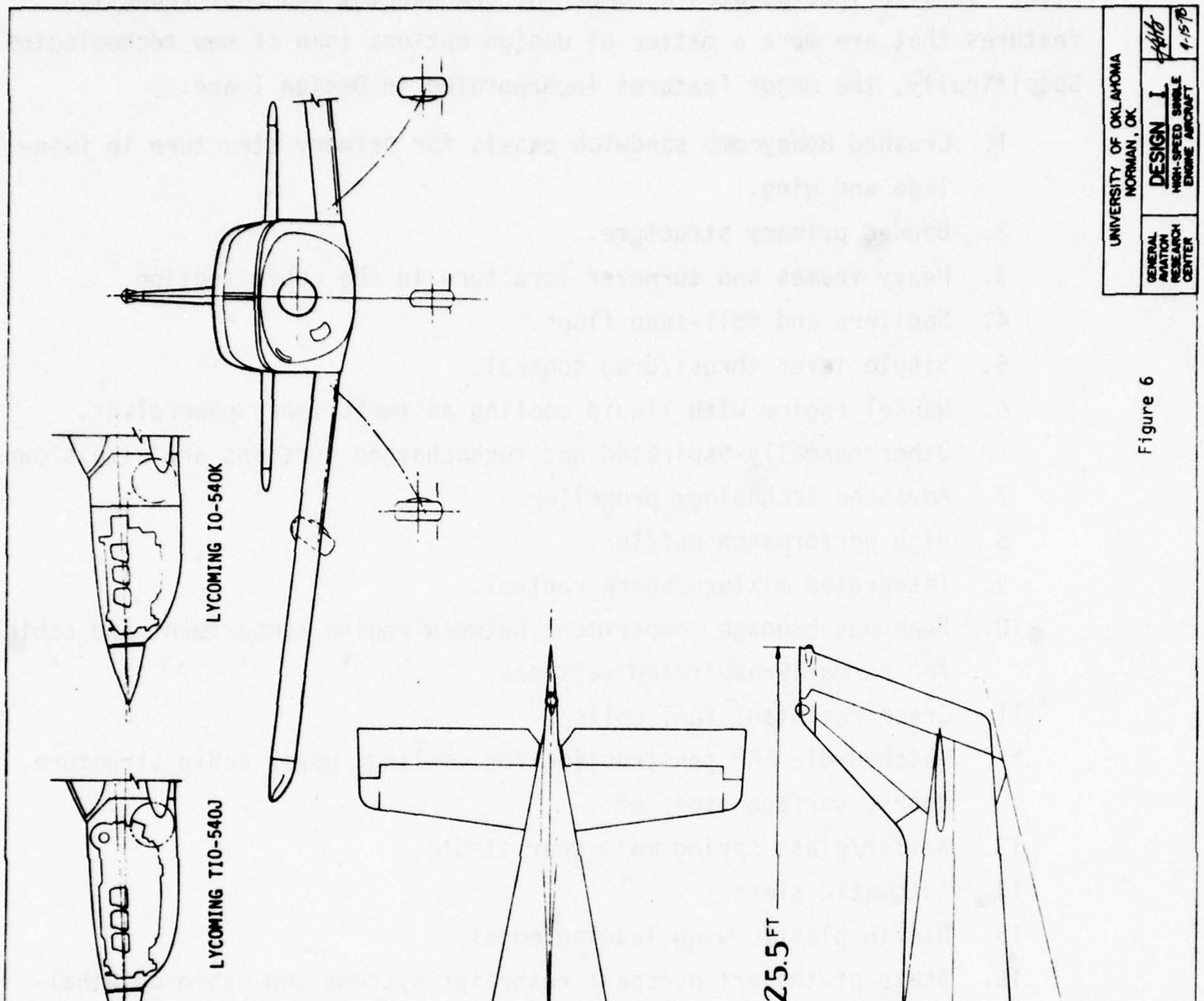
TABLE 5 Correlation between Social/Political Trends and Selected Designs

risk. It also incorporates a number of crashworthy and cost-reduction features that are more a matter of design options than of new technologies. Specifically, the major features incorporated in Design I are:

1. Crushed honeycomb sandwich panels for primary structure in fuselage and wing.
2. Bonded primary structure.
3. Heavy frames and turnover structure in the cabin section.
4. Spoilers and full-span flaps.
5. Single lever thrust/drag control.
6. Wankel engine with liquid cooling as the primary powerplant. Other normally-aspirated and turbocharged versions are also shown.
7. Advanced technology propeller.
8. High performance muffler.
9. Integrated mixture/spark control.
10. Generous baggage compartment between engine compartment and cabin for normally-aspirated versions.
11. Crash resistant fuel cells.
12. Matched-die FRP construction for cowling, upper cabin structure, doors, surface tips, etc.
13. Kevlar/glass spring main gear struts.
14. Automatic slats.
15. Olefin plastic wing leading edges.
16. State-of-the-art occupant restraint systems and cabin delethalization.
17. Full set of advanced avionics and instrumentation as available.

The relatively small wing area (130 square feet) and particular attention to cooling drag and interference losses should enable the airplane to outperform current production aircraft while maintaining a comfortable cabin and generous baggage volume. With the installation of high output engines, speed performance would be at or above world record levels.

Figure 8 shows the speed performance versus altitude for two versions of Design I, one the normally-aspirated Wankel and the other the turbocharged Continental GTS10-520H. The two plots illustrate the very significant improvements that can be achieved through turbocharging and, in this case, a 25% increase in rated power.


UNIVERSITY OF OKLAHOMA
NORMAN, OK
GENERAL AVIATION RESEARCH CENTER
DESIGN I
HIGH-SPEED SINGLE ENGINE AIRCRAFT
LYCOMING IO-540K
LYCOMING TIO-540J
CONTINENTAL GTSIO-520H
CONTINENTAL GTSIO-520F
CURTISS-WRIGHT RC-75-2
28.0FT
25.5FT
Figure 6

SPECIFICATIONS AND PERFORMANCE

DESIGN I

HIGH-SPEED SINGLE ENGINE AIRCRAFT

	LYCOMING IO-540K	CURTISS-WRIGHT RC-75-2	LYCOMING TIO-540J	CONTINENTAL GTSIO-520H	CONTINENTAL GTSIO-520F
SPECIFICATIONS					
HORSEPOWER	300	300	350	375	435
RPM	2700	2200	2575	2275	2275
CRITICAL ALTITUDE (ft)	S.L.	S.L.	15,000	20,000	20,000
GROSS WEIGHT (lbs)	3040	2980	3100	3130	3220
EMPTY WEIGHT (IFR)(lbs)	1700	1640	1760	1790	1880
USEFUL LOAD (lbs)	1340	1340	1340	1340	1340
WING SPAN (ft)	28.0	28.0	28.0	28.0	28.0
WING AREA (sq ft)	130	130	130	130	130
LENGTH (ft)	25.5	25.5	25.5	25.7	25.7
PROPELLER DIA (ft)	6.7	7.0	6.7	7.2	7.2
POWER LOADING (lbs/HP)	10.1	9.9	8.9	8.3	7.4
WING LOADING (lbs/sq ft)	23.4	22.9	23.8	24.1	24.8
SPAN LOADING (lbs/ft)	108.6	106.4	110.7	111.8	115.0
FUEL CAPACITY (lbs)	600	600	600	600	600
PERFORMANCE					
TOP SPEED (S.L.)(k)	202	205	211	213	224
TOP SPEED (ALT)(k)	-	-	248	263	277
BEST ALTITUDE (ft)	-	-	20,000	20,000	20,000
CRUISE SPEEDS (ALT)(ft)	8500	8000	27,000	27,000	27,000
75% POWER (k)	193	196	234	249	262
65% POWER (k)	184	187	223	235	247
55% POWER (k)	174	177	203	214	225
STALL SPEED (V_{s1})(k)	65	65	66	66	67
STALL SPEED (V_{sf})(k)	53	53	54	54	54
T.O. DISTANCE (ft)	1300	1300	1100	1100	1020
LANDING DISTANCE (ft)	1100	1100	1160	1160	1210
R/C (S.L.)(ft/min)	1900	1950	2300	2300	2900
SERVICE CEILING (ft)	23,000	23,000	32,700	34,200	36,500
RANGE (75%)(nm)	870	870	925	890	850
RANGE (55%)(nm)	1030	1030	1095	1025	975

TABLE 6. Design I Specifications.

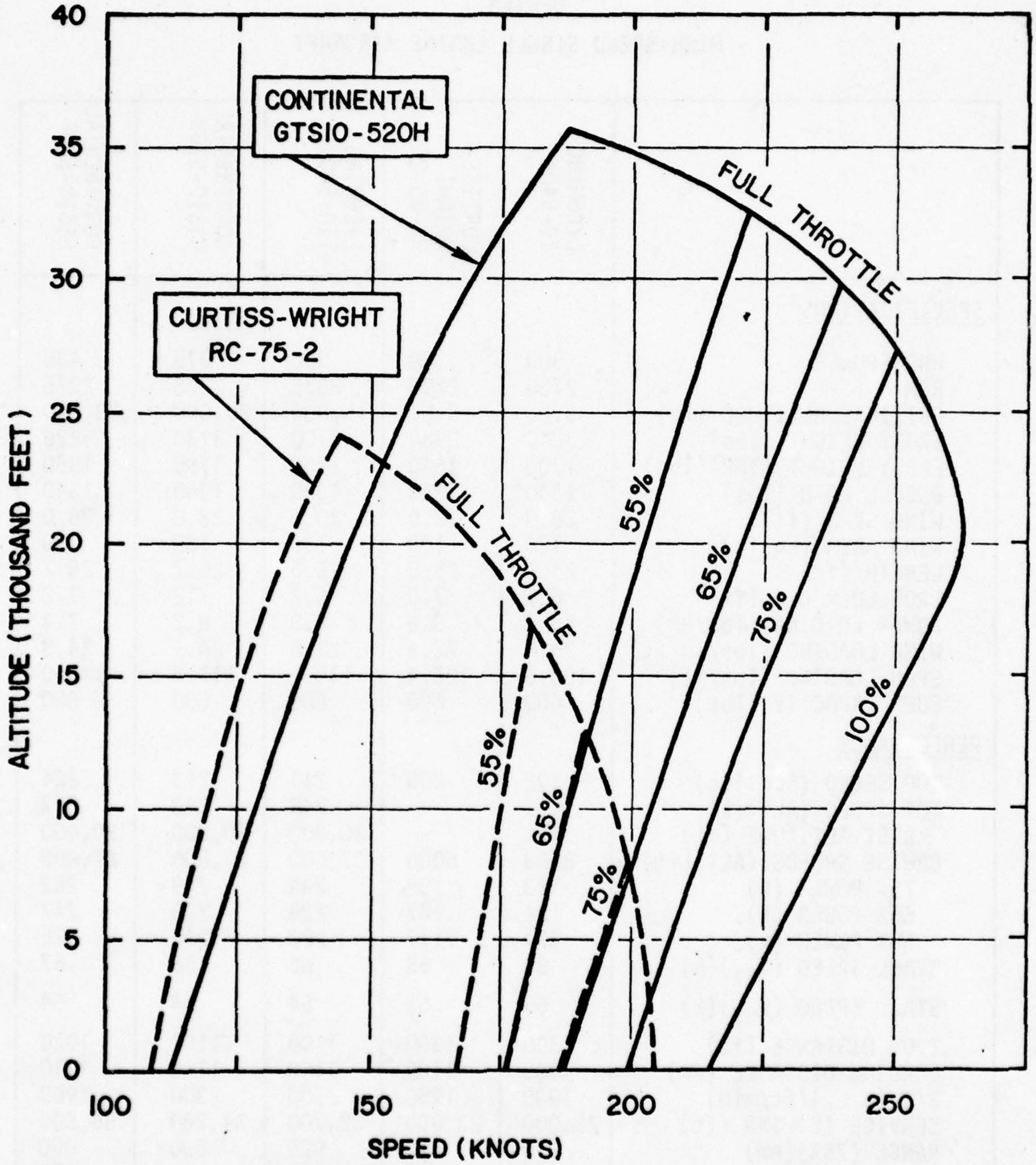


Figure 7. Altitude Performance Curves
Design I

DESIGN II

The increasing reliability of turbine engines makes it possible to think in terms of high-performance single-engine aircraft. The potential economies are large. The major objection to single-engine aircraft for IFR and night flying is something known as peace-of-mind. There is some evidence, however, that the peace-of-mind problem may be more a matter of perception than a true reflection of the odds. It is not at all clear that NTSB statistics confirm the safety of twin engine aircraft relative to singles. There is, in fact, a growing body of statistics and comment that seem to show that "twin-engine safety" may be more myth than fact. Further quantitative studies of the situation would be desirable. In the meantime, it is clear that a number of trends are leading the industry to more sophisticated singles with full IFR and night-flying capabilities.

Design II, shown in Figure 9, is one possible configuration for a single-engine turbofan. As with Design I, the layout is conventional, but an effort has been made to reduce wetted area without compromising cabin volume. A five seat configuration was chosen to accomodate a single professional pilot with owner co-pilot or with four passengers, both fairly common passenger loads.

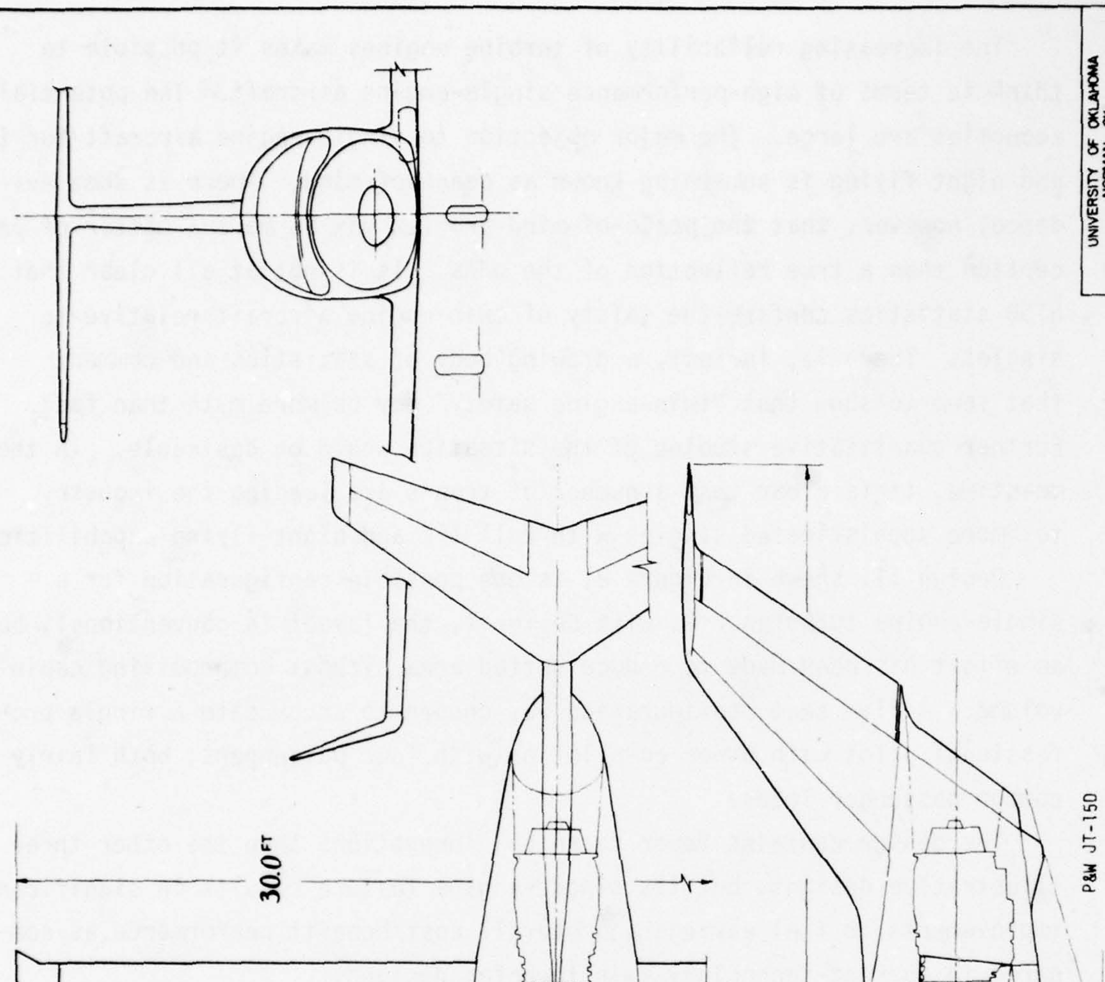
The design contains fewer technical innovations than the other three illustrative designs, but its single-engine feature results in significant improvements in fuel savings and overall cost/benefit performance as compared to current-technology twin turbofan designs.

Figure 9 shows thrust and drag characteristics versus airspeed for Design II, and Table 7 shows a comparison between its specifications and performance and those of a current-technology twin turbofan.

Some of the design and advanced technology features of Design II are:

1. Spoilers and full span flaps.
2. Crushed honeycomb sandwich panels for primary structure in wing and fixed tail surfaces.
3. Crash resistant fuel cells.
4. Ice shedding leading edges.
5. Full set of advanced avionics and instrumentation as available.

If present R & D programs result in low cost turbines in the 1000-1500 pound (450-680 kg) thrust range, the same basic design could be fitted



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DESIGN II
SINGLE-ENGINE TURBOFAN

4-15-78

Figure 8

TABLE 7. Design II Comparison with Current Technology Turbofan

	SINGLE ENGINE TURBOFAN	CURRENT TECHNOLOGY TWIN TURBOFAN
<u>SPECIFICATIONS</u>		
SEA LEVEL THRUST (lbs)	2,200	4,400
GROSS WEIGHT (lbs)	6,200	11,800
EMPTY WEIGHT(1) (lbs)	3,350	6,600
USEFUL LOAD (lbs)	2,850	5,200
WING SPAN (ft)	30.0	48
WING AREA (sq ft)	150	270
LENGTH (ft)	32.2	44
THRUST LOADING (lbs/lb)	2.8	2.7
WING LOADING (lbs/sq ft)	41.3	43.7
SPAN LOADING (lbs/ft)	207	246
FUEL CAPACITY (lbs)	1,900	3,800
SEATS	2 + 3	2 + 5
<u>PERFORMANCE</u>		
MAX. CRUISE SPEED (k)(30,000 ft)	402	380
90% CRUISE SPEED (k)(20,000 ft)	370	350
STALL SPEED (flaps up)(k)	92	93
STALL SPEED (flaps down)(k)	74	80
BALANCED FIELD LENGTH (ft)(ISA)	2,600(3)	2,900
RATE OF CLIMB (S.L.)(ft/min)	3,750	3,300
SERVICE CEILING (G.W.)(ft)	43,000	43,000
RANGE(2) (90% cr, 3,5000')(nm)	1,390	1,315
RETAIL PRICE ($)(1978)	575,000	975,000

(1) Equipped for IFR

(2) 45 min. reserve

(3) T.O distance over 50' obstacle

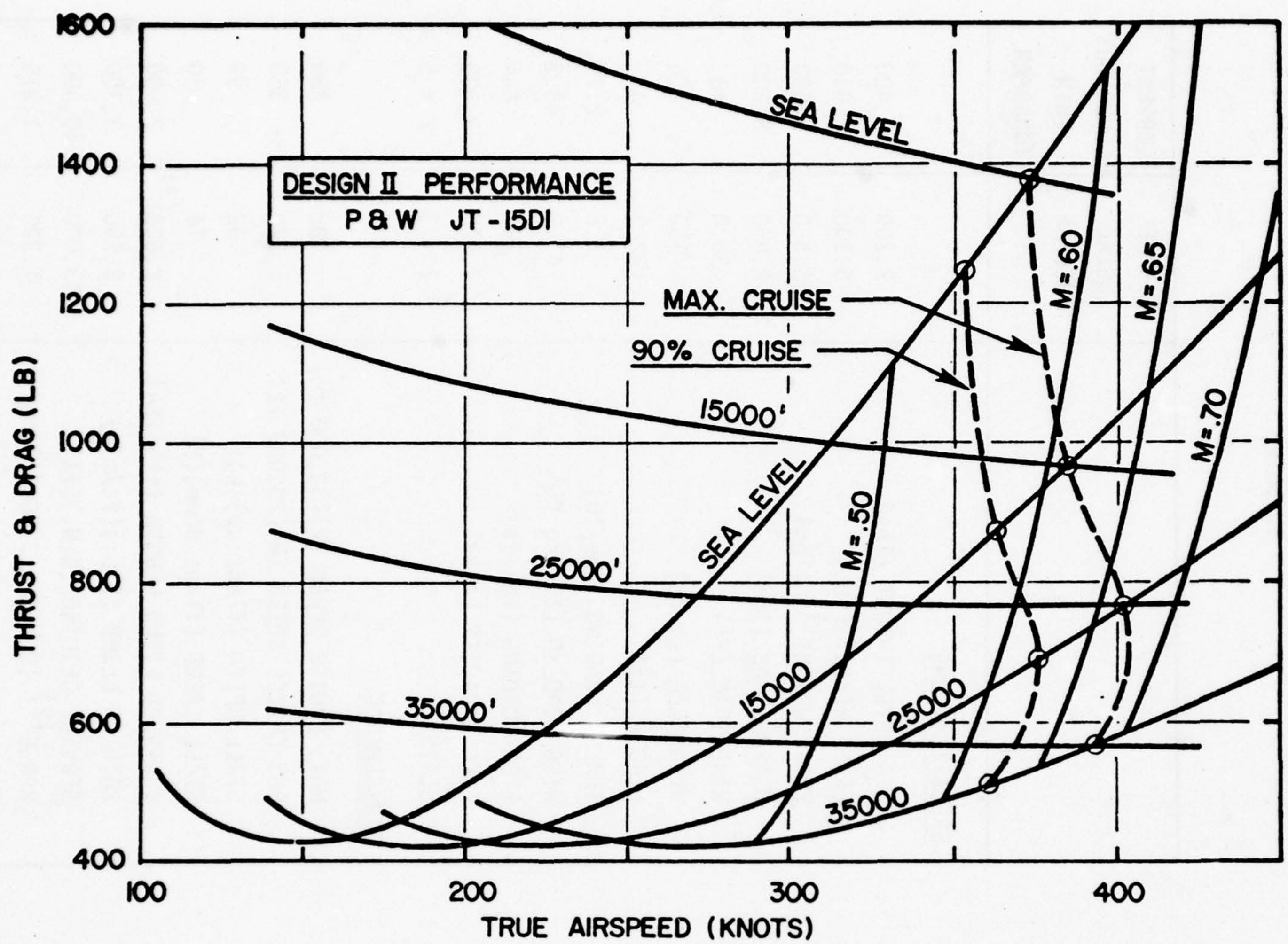


Figure 9. Thrust and Drag, Design II

with two fans in the ever-popular aft-mounted position. Performance for a given installed thrust would be reduced slightly from that of the single-engine version.

DESIGN III

Design III, shown in Figure 10, capitalizes on two major opportunities; a significant improvement in crashworthiness and a maximum use of potentially low cost matched-die molded parts. It also illustrates one way in which canard surfaces can be used to achieve specific design objectives.

The improved crashworthiness results from the aft placement of the cabin and the strong surrounding structure, including the thick wing root. With sacrificial structure surrounding the cabin on all sides, the likelihood of severe cabin deformation or penetration is reduced for most crash situations. Progressive breakup of the forward fuselage and the outer wing panels will tend to reduce cabin deceleration and permit the passenger restraint systems and cabin delethalization features to perform as intended.

The configuration lends itself to matched die molding because of the low aspect ratio wing, short fuselage and thick surfaces. The resulting low stress levels due to shear, torsion, and bending moments are compatible with the lower allowables of random orientation matched-die parts.

Although the wing area of Design III is relatively large, the wetted area is similar to that of conventional designs, and the cruise performance would therefore be competitive. The reduced span has an adverse effect on induced drag, however, and the rate-of-climb suffers slightly.

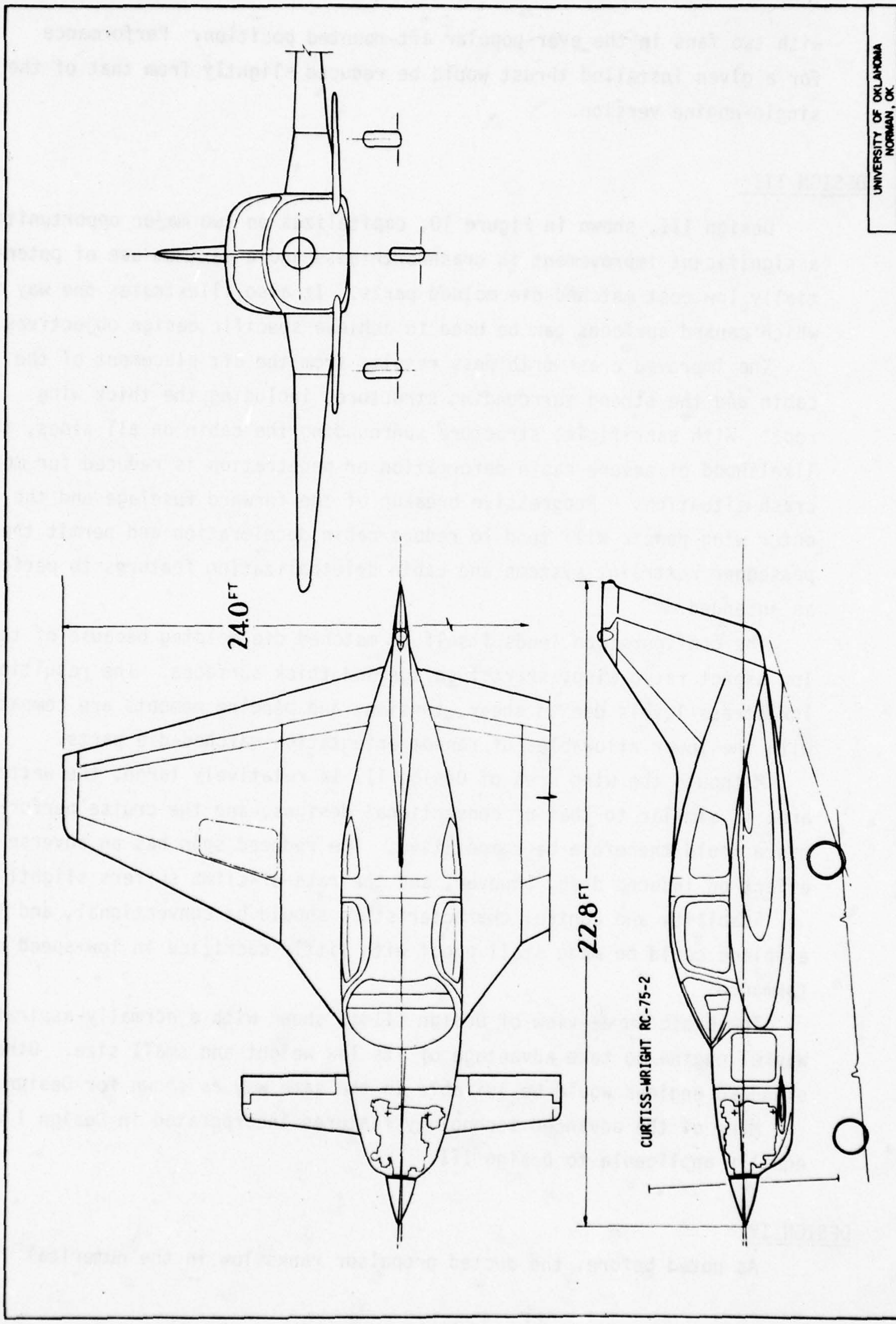
Stability and control characteristics should be conventional, and the airplane could be made stall proof with little sacrifice in low-speed performance.

The basic three-view of Design III is shown with a normally-aspirated Wankel engine to take advantage of its low weight and small size. Other standard engines would be suitable in the same way as shown for Design I.

Many of the advanced technology features incorporated in Design I are equally applicable to Design III.

DESIGN IV

As noted before, the ducted propulsor ranks low in the numerical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DESIGN III
SINGLE-ENGINE CRASHWORTHY AIRCRAFT
24.0 FT
22.8 FT
CURTISS-WRIGHT RC-75-2

Figure 10

SPECIFICATIONS AND PERFORMANCE
DESIGN III
SINGLE-ENGINE CRASHWORTHY AIRCRAFT

	LYCOMING 10-540K	CURTISS-WRIGHT RC-75-2	CONTINENTAL GTS10-520H
SPECIFICATIONS			
HORSEPOWER	300	300	375
RPM	2700	2200	2275
CRITICAL ALTITUDE (ft)	S.L.	S.L.	20,000
GROSS WEIGHT (lbs)	3080	3020	3170
EMPTY WEIGHT (IFR)(lbs)	1740	1680	1830
USEFUL LOAD (lbs)	1340	1340	1340
WING SPAN (ft)	24.0	24.0	24.0
WING AREA (sq ft)	195	195	195
LENGTH (ft)	22.8	22.8	23.4
PROPELLER DIA (ft)	6.7	7.0	7.0
POWER LOADING (lbs/HP)	10.3	10.1	8.5
WING LOADING (lbs/sq ft)	15.8	15.5	16.3
SPAN LOADING (lbs/ft)	128.3	125.8	132.1
FUEL CAPACITY (lbs)	600	600	600
PERFORMANCE			
TOP SPEED (S.L.)(k)	185	189	202
TOP SPEED (ALT)(k)	-	-	245
CRUISE SPEEDS (ALT)(ft)	8500	8000	20,000
75% POWER	168	172	230
65% POWER	160	164	219
55% POWER	152	155	207
STALL SPEED (V_{S_1})(k)	64	63	65
STALL SPEED (V_{S_F})(k)	50	50	51
T.O. DISTANCE (ft)	1300	1300	1100
LANDING DISTANCE (ft)	1050	1050	1100
R/C (S.L.)(ft/min)	1100	1150	1600
SERVICE CEILING (ft)	21,000	21,000	33,000
RANGE (75%)(nm)	800	800	790
RANGE (55%)(nm)	940	940	910

TABLE 8.

evaluation because it is heavier and more complex than a conventional propeller. It succeeds only if a disproportionate value is placed on noise control. The fact that this high value may be imposed as a matter of public policy makes the ducted propulsor a particularly interesting new technology and one that deserves some attention.

Since commuter aircraft operating from close-in airports are the most likely early target of noise restrictions, it seemed reasonable to investigate this class of general aviation aircraft. A number of configurations involving two, three, and four engine combinations were considered.

The ducted propulsor, as presently envisioned, is intended to operate with conventional reciprocating or rotary internal combustion engines. The combination of engine and propulsor is relatively heavy, imposing balance problems in addition to aerodynamic interference problems between the propulsor ducts and the wings and tail surfaces.

Design IV, shown in figure 12, appeared to be one of the most promising approaches. The canard configuration works out well for the aft-mounted engine option and its associated rearward center of gravity. It also provides a good relationship between propulsors and wings, a long wheelbase, and easy loading conditions for both passengers and cargo.

The cabin is laid out for 11 passenger seats with a pitch of 33 inches. The center aisle width is 15 inches and there is space for additional baggage and a toilet at the rear of the fuselage. Cabin volume in the all-cargo configuration is approximately 420 cubic feet.

Design IV represents a reasonable upper limit on size and weight for engines that are currently available in the 400-450 hp (300-336 kw) range. Although it is capable of meeting the performance requirements of SFAR 23, there is some question as to whether or not it could meet the more stringent requirements of FAR 25 with the specified power.

The advanced technology features of Design IV, in addition to those already mentioned, are:

1. Single-lever thrust/drag control for steep appraoches.
2. Crash resistant fuel cells.
3. Crash resistant cabin structure through the use of advanced analysis techniques.
4. Crushed honeycomb sandwich panels for wing and canard surfaces.
5. A full complement of advanced instrumentation and avionics as available.

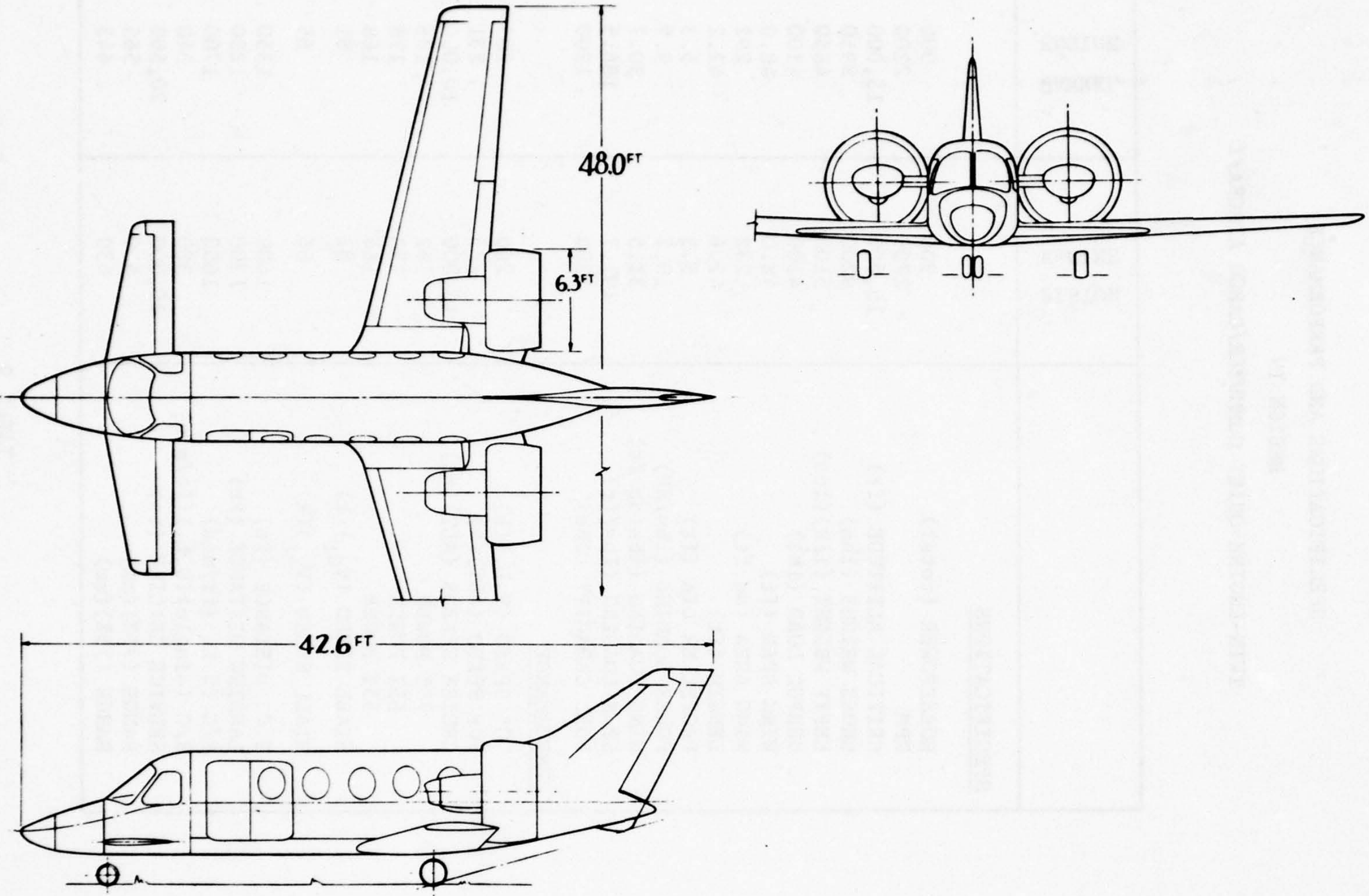

Figure 11

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DESIGN IV
TWIN-ENGINE QUIET COMMUTER/CARGO AIRCRAFT

9-15-78

SPECIFICATIONS AND PERFORMANCE

DESIGN IV

TWIN-ENGINE QUIET COMMUTER/CARGO AIRCRAFT

	PISTON ENGINE	WANKEL ENGINE
SPECIFICATIONS		
HORSEPOWER (total)	900	900
RPM	2700	2200
CRITICAL ALTITUDE (ft)	15,000	15,000
GROSS WEIGHT (lbs)	9200	8950
EMPTY WEIGHT (IFR)(lbs)	5100	4850
USEFUL LOAD (lbs)	4100	4100
WING SPAN (ft)	48.0	48.0
WING AREA (sq ft)	292	292
LENGTH (ft)	42.6	42.2
PROPELLER DIA (ft)	5.3	5.3
POWER LOADING (lbs/HP)	10.2	9.9
WING LOADING (lbs/sq ft)	31.5	30.7
SPAN LOADING (lbs/ft)	191.7	186.5
FUEL CAPACITY (lbs)	1200	1200
PERFORMANCE		
TOP SPEED (S.L.)(k)	200	205
TOP SPEED (ALT)(k)	225	231
CRUISE SPEEDS (ALT)(ft)	10,000	10,000
75% POWER	182	186
65% POWER	173	178
55% POWER	164	168
STALL SPEED (V_{S_1})(k)	82	81
STALL SPEED (V_{S_f})(k)	66	65
T.O. DISTANCE (ft)	1400	1350
LANDING DISTANCE (ft)	1300	1250
R/C (S.L.)(ft/min)	1600	1700
R/C (single)(S.L.)(ft/min)	300	340
SERVICE CEILING (ft)	20,000	20,500
RANGE (75%)(nm)	550	565
RANGE (55%)(nm)	630	645

TABLE 9.

The Design IV configuration could accomodate high bypass ratio turbines as well as ducted propulsors. With the removal of the power limit imposed by current reciprocating and rotary engines, the design could easily meet the FAR 25 performance requirements. It could also be enlarged to provide a more realistic capacity of 20 to 30 passengers.

In many ways, commercial aircraft design is a conservative process. Since safety must be a first consideration in all design decisions, it is important that new features be proved before being incorporated into new or existing aircraft. Otherwise, new technologies and design approaches could create as many problems as they solve.

This important consideration must be kept in mind when thinking about the future of new technologies. It is one thing to recognize the potential for new approaches and new products. It is quite another to recommend that they be incorporated immediately into production aircraft. The links between their potential and the marketplace are research, development, and demonstration.

IX CONCLUSIONS

This study has attempted to assess the merits of a number of new technologies for application to general aviation aircraft. Its purpose is also to investigate the potential for a technology demonstration program aimed specifically at the needs of general aviation. Government support for aircraft research and development has been a major factor in the growth and accomplishments of the aircraft industry in the past. Demonstration programs involving the FAA, NASA, and industry could encourage the development of new technologies and increase the rate of technology transfer in the general aviation industry. They could also serve to define and clarify the certification process for new technologies and thereby ease and expedite their introduction into general use.

On the basis of the study results, the following conclusions appear to be justified.

1. Of the large number of new technologies that could be used in general aviation, somewhere between 40 and 50 have considerable potential for improving general aviation safety and efficiency. Social and political pressures will also influence the future of the general aviation industry. This report identifies twenty-two trends that appear to be particularly important in determining the likely directions for technical change in the industry.

2. A numerical method for judging the relative merits of candidate technologies has been developed and used in this study. It appears to be useful for ranking widely different technical options.

3. It is possible to design technology demonstration aircraft that can incorporate most of the high-ranking new technologies in ways that will be useful for assessing their value in practice.

4. Responsible individuals in the general aviation industry have shown a high level of interest in this assessment and in the application of new technologies to general aviation design. Furthermore, the general aviation community appears to be much more open to cooperative ventures with government agencies than it has been in the past.

5. The degree of interest on the part of engineering managers justifies further consideration of technology demonstration programs for general aviation. Specifically, it would be valuable to establish the interest at other levels of management and to determine the liklihood of reaching a consensus on the nature and extent of such programs.

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APPENDIX A

DELETED TECHNOLOGIES

As noted in Section IV of this report, a number of technologies were deleted from the original list for one or more of the reasons defined by the five elimination criteria. A discussion of a few of the most interesting of the deleted technologies follows.

1. FLYING AUTOMOBILES

The concept has always been attractive. Parking the airplane part of the vehicle at the airport and driving the car to the city, or parking the airplane by the side of the road and driving to one's destination in unflyable weather has challenged designers for half a century. There are disadvantages, of course. The airplane combination will not fly as well as an airplane or drive as well as an automobile. It will also tend to be expensive, and the logistics of separating, securing, and eventually recombining the units present problems that have not been entirely solved.

These disadvantages remain despite the fact that some talented individuals have devoted a major part of their career to the development of flying automobiles and have built widely demonstrated and workable prototypes. Flying automobiles have not found a market primarily because readily available rental cars appear to have more appeal for most aircraft owners. Even though research and development on flying automobiles will probably continue, the potential impact on general aviation design appears to be small.

2. VERTICAL TAKE OFF AND LANDING

Like flying autos, the vision of vertical take off followed by conversion to high speed cruise has been persuasive, but remarkably unsuccessful. The energy requirements for vertical take off are very high compared to conventional aircraft and the economies are correspondingly poor. In addition, the conversion phase has caused major

difficulties even in the hands of professional test pilots. The evidence suggests that the VTOL/cruise aircraft have accident rates that are unacceptable even to the military. Under these circumstances, the potential for VTOL aircraft in general aviation appears to be very close to zero.

3. SUPERSONIC GENERAL AVIATION TRANSPORTS

The likelihood of a second generation SST appears to be very low. On the other hand, it is interesting to note that the things an SST does well, transporting premium cargo at very high speed, are features that might be attractive to corporate owners. Putting aside the arguments of fuel efficiency and other environmental factors, it is reasonable to argue that if there is going to be any commercial supersonic development, the most promising avenue might be toward a relatively small supersonic general aviation transport. Its size would tend to reduce development cost and would also tend to limit environmental impacts. Much of the hardware needed for such development is already available from military and commercial programs, and the corporate buyers could probably justify the additional expense on the basis of management productivity.

This is not to suggest that such a development is either timely or feasible, but if there are to be commercial supersonic programs in the future, it appears that a business jet SST might be a promising candidate.

4. WIND SHEAR DETECTOR

Recent airline landing accidents under conditions of extreme turbulence and wind shear have focused the attention of aeronautical engineers and meteorologists on the problem of detecting and responding to such potentially dangerous conditions. As it turns out, the response of an airplane to input gusts is determined by the phugoid damping factor, which is proportional to landing velocity squared and drag coefficient, and is inversely proportional to wing loading. Calculations show that the damping factor for small aircraft is

higher than that of large jets. Thus, most general aviation aircraft are not likely to experience the same difficulty with wind shear. This conclusion is bourne out by the fact that three minutes before Eastern Flight 66 (a Boeing 737) crashed at New York's Kennedy airport on June 24, 1975, a Beechcraft Baron made a successful landing, even though it experienced a heavy sink rate and air speed drop of 20 knots.

Since the presently-favored wind shear detectors are ground based, it does not appear that their eventual use will affect the design of general aviation aircraft, although their availability will certainly improve the safety record for landings and take-offs in adverse weather.

5. LOW-COST COLLISION AVOIDANCE

Technical developments in the field of low-cost collision avoidance are not promising for general aviation. A majority of mid-air collisions occurs in the vicinity of airports, many of them uncontrolled, and involve aircraft at the low-speed and low-cost end of the general aviation spectrum. Because of difficulties with nuisance warnings in congested areas, the universial adoption of collision avoidance systems could result in a net hazard rather than a safety benefit. The history of a relatively more simple device, the crash locater beacon, is instructive in this connection.

6. AUTOMATED FABRICATION

Aircraft production falls midway between hand-built craftsmanship and the automated transfer lines of Detroit. It is clear that the cost of general aviation aircraft could be reduced by taking advantage of the production techniques developed by the automotive industry. Unfortunately, the very high capital cost of the necessary equipment can be justified only by production rates at least an order of magnitude greater than those of today's general aviation industry. Even the most optimistic members of the aviation community have not suggested

that such production rates are possible.

For the forseeable future, medium production technologies such as automatic riveting, tape controlled machines, fiberglass-based composites and structural bonding will continue to be the major weapons in the battle to lower the cost and improve the quality of general aviation aircraft.

7. LOW COST PRESSURIZATION

Lower cost pressurization would be attractive for medium performance aircraft, but the prospects seem remote. Structural requirements are not likely to be reduced. In fact, an increasing awareness of fatigue effects and the economic benefits of long-life airframes will tend to make structural requirements more stringent. Valves and controllers are not a large part of pressurization costs. The pressurization source will continue to be from turbochargers or from high-pressure bleed air, neither of which is subject to major cost reduction.

The use of pressurization will continue to expand in the general aviation market, but the cost and maintenance penalties will continue to be very much as they are today.

8. ANGLE OF ATTACK INDICATORS

Angle-of-attack indicators are not likely to play a large role in the future of general aviation. Useful for optimizing the flight of large, heavy and fast aircraft, their value to the smaller general aviation aircraft is less clear. A relatively low cost system (Monitaire) was marketed extensively in the 1960's with little success. At the present time, the high cost of angle-of-attack indicator systems is a major limitation on their wider use in the general aviation fleet.

9. LOW COST FUEL METERING

Accurate fuel metering units are now available for all classes of general aviation aircraft at prices ranging from $1000 to $2000.

All use turbine sensor units with various electronic processors to convert raw data to information on flow rates, fuel used, fuel remaining and the like. Other sensing principles are used in commercial units (vortex flow, oscillating ball), but none are currently less expensive than the turbine units.

The prospects for low cost ($100-$300) fuel flow systems are not promising. Low production volume, the special requirements for aircraft use, and the need for FAA certification and inspection all exact their price. A large-scale market for automotive units would provide an improved production base.

10. LOW COST MEDIUM TURBINES

Since turbines are already available in the higher thrust and horsepower ranges, new low-cost units would merely replace existing units. Barring major breakthroughs, low cost is likely to be achieved through compromises in reliability and thermal efficiency unless it occurs slowly through a trickle-down process from heavily-funded military programs. As noted earlier, corporate owners have not been deterred by cost in their search for high levels of safety, reliability and performance. The impetus for a major program in this area seems to be lacking.

Component development such as ceramic blades and cheaper alloys could be of great benefit to all classes of turbine engines.

APPENDIX B

The following individuals were helpful in tracking down information on products and technologies. Many also made suggestions on the original lists of technologies and social/political trends. Their help was essential in avoiding oversights and in putting the various technologies in perspective. The author acknowledges their valuable contributions and reiterates his earlier disclaimer that the opinions, omissions and errors of the report are entirely his own, and that the views do not necessarily reflect those of the FAA or of any single contributor.

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